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Soil Classification for Construction Practice in Shallow Trenching

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NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Director*

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by

F. Y. Yokel, R. L. Tucker, and L. C. Reese

ABSTRACT

Construction practices in trenching and data on potential causes of
trenching accidents are reviewed. A study is made of the soil properties
and site conditions that must be identified in order to determine the
stability of shored and sloped excavations against cave-ins. Two pos-
sible alternate soil classification methods are recommended. The
methods are simple enough to be used by construction foremen and at the
same time use parameters which can be measured or identified without
ambiguity. The classification methods are supplemented by appropriate
field tests and correlated with allowable side slopes and lateral soil
pressures on shoring.

Keywords: Braced excavations; construction; excavation; geotechnical
           engineering; retaining structures; shoring; slope stability;
           soil classification; soil pressure; soil testing; trenching.

COVER: *Trenchbox used to protect workers at the bottom of a sloped
         excavation in sandy soil*

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PREFACE

In June 1976 the Occupational Health and Safety Administration (OSHA) engaged the National Bureau of Standards (NBS) to study the provisions for Excavation, Trenching and Shoring of the Safety and Health Regulations for Construction [9][1] and to recommend potential modifications that could improve their effectiveness. As part of this study, a team from The University of Texas at Austin studied the problem of soil classification under an NBS Contract and submitted a study report in January 1979 [22]. In a National workshop at the Department of Labor in September 1978 [11a] the preliminary findings of the NBS study, including preliminary recommendations of the Texas study were reviewed and discussed by working groups consisting of contractors, union representatives, consulting engineers, and government officials.

The recommendations presented in this report are based on analytical and field studies by NBS, the University of Texas report, and recommendations and comments made in the workshop.

The report was prepared by the geotechnical Engineering Group of the Center for Building Technology.

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[1]Numbers in brackets identify literature referenced in Section 7.

EXECUTIVE SUMMARY

As a result of a National Bureau of Standards' study of the problems associated with excavation safety, it has been concluded that there is a need for a simple soil classification system that can be used by field supervisors to make rapid decisions on sloping or shoring requirements. The soil classification system should meet the following criteria: it should be comprehensive (cover essentially all the conditions that could be encountered); it should consider (at least implicitly) all the critical conditions that can cause instability; it should not be ambiguous (two persons classifying a site should arrive at the same conclusion); it should be usable by construction supervisors and OSHA compliance officers in the field without the assistance of an engineer.

Two alternative systems are proposed for consideration; The "Simplified Classification System" and the "Matrix Classification System." The simplified system requires fewer decisions by construction supervisors, but it also somewhat narrows the number of choices available to contractors. The matrix system is more sophisticated and would require better training of construction personnel and OSHA inspectors. The systems are summarized in Tables 1, 2, and 3. The tables contain definitions of soil types as well as stability requirements associated with the various soil types identified. Lateral loads that shoring systems should be designed to resist are defined by the "lateral weight effect" w_e and further explained in Figure 1. Recommended allowable configuration of sloped excavations associated with the steepest allowable side slopes defined in Tables 1 and 3 are shown in Figure 2.

The soil classification systems are also correlated with provisions for spaced sheeting (skip shoring). Simple field identification methods are recommended which can be used to determine the soil type (or class) in the field. These consist of a visual-manual identification method, supplemented when necessary by in-situ strength tests using a pocket penetrometer[2] or a hand operated shearvane and by a drying test which is performed on an undisturbed sample and used to determine whether the soil is fissured and whether it is cohesive or granular. In case of doubt or dispute these simple field tests can be further corroborated by traditional in-situ and laboratory tests.

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[2] The Pocket Penetrometer is a small (vest-pocket sized) commercially available device that measures in-situ shear strength of cohesive soils.

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Table 1. Simplified Soil Classification System

Soil Type	Description	w_e lb/ft^3[a]	Steepest Slope hor.: vert.
A	Intact Hard	20	3/4:1
B	Medium	40	3/4:1
C	Submerged or Soft	80	1 1/2:1

1. <u>Intact Hard Soils</u> (Type A) include stiff clay and cohesive or cemented sands and gravels (hardpan, till)[b] above the groundwater table which have no fissures, weak layers, or inclined layers that dip into the trench. Stiff clays included have an unconfined compressive strength (pocket penetrometer reading) q_u = 1.5 tsf[c] or more. Intact hard soils subject to <u>vibrations</u> by heavy traffic, pile driving or similar effects are <u>Type B</u>.

2. <u>Medium Soils</u> (Type B) are all soils which are not Type A or C.

3. <u>Soft Soils (Type C)</u> include cohesive soils[b] with an unconfined compressive strength (pocket penetrometer reading) of 0.5 tsf[c] or less and soils that cannot stand on a slope of 3 hor. in 1 vert. without slumping (muck).

4. <u>Submerged Soils</u> (Type C) are assumed whenever water drains into the trench from the soil forming the bank, or water is retained by tight sheeting, or there is a possibility that the trench may be fully or partially flooded before workers leave it or may be entered by workers within 6 hours after more than half of its depth was flooded and pumped out.

5. <u>Fractured Rock</u> shall be considered Type B when it is dry and Type C when it is submerged. Intact rock is exempt from shoring and sloping requirements.

6. <u>Layered Systems</u> (two or more distinctly different soil or rock types, micaceous seams in rock) which dip toward the trench wall with a slope of 4 hor.: 1 vert. or steeper are considered Type C. Layered soils are classified in accordance with the weakest layer.

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[a] 1 lb/ft^3 = 1.63 N/m^3

[b] Cohesive Soils are clays (fine grained) or soils with a high clay content which have cohesive strength. They do not crumble, can be excavated with vertical side slopes, are plastic (can be molded into various shapes and rolled into threads) when moist and are hard to break up when dry.

[c] 1 tsf = 96 kPa

Table 2. Matrix Classification System

Site Condition	Water in Trench			
	No		Yes	
	Fissures		Fissures	
Soil	No	Yes	No	Yes
Stiff Cohesive[a]	I	II	III	
Medium Cohesive	II	III	III	IV
Granular[b]	II		III	
Soft	IV		IV	

Notes

1. <u>Water in Trench</u> is assumed whenever water drains into the trench from the soil forming the bank, or water is retained by tight sheeting, or there is a possibility that the trench may become fully or partially flooded before workers leave it or may be entered by workers within 6 hours after more than half its depth was flooded and pumped out.

2. <u>Vibrations</u>: soils subjected to vibrations by heavy traffic, pile driving or similar effects shall <u>always</u> be assumed fissured.

3. <u>Stiff Cohesive Soils</u>[a] include stiff clays and cohesive or cemented sands and gravels (till, hardpan). Stiff clays included have an unconfined compressive strength (pocket penetrometer reading) $q_u = 1.5$ tsf[c] or larger.

4. <u>Medium Cohesive Soils</u>[a] have an unconfined compressive strength (pocket penetrometer reading) between 0.5 and 1.5 tsf[c].

5. <u>Granular Soils</u>[b] are gravels, sands and silts that can stand on a slope steeper than 3 hor.: 1 vert. without spalling or slumping.

6. <u>Fractured Rock</u> shall be treated as granular soil. Intact rock is exempt from shoring and sloping requirements.

7. <u>Soft Soils</u> are cohesive soils with an unconfined compressive strength (pocket penetrometer reading) of 0.5 tsf[c] or less and silts that can not stand on a slope of 3 hor.: 1 vert. without spalling or slumping (muck).

8. <u>Layered Systems</u> (two or more distinctly different soil or rock types, micaceous seams in rock) which dip toward the trench wall with a slope of 4 hor.: 1 vert. or steeper are considered <u>Class IV</u> soils.

9. Disturbed Cohesive Soils (backfill) shall be treated as fissured
    medium cohesive or soft cohesive soils

---

a/ Cohesive soils are clays (fine grained) or soils with a high clay
    content which have cohesive strength. They do not crumble, can be
    excavated with vertical sideslopes, are plastic (can be molded into
    various shapes and rolled into threads) when moist and are hard to
    break up when dry.

b/ Granular Soils have no cohesive strength. They normally cannot be
    excavated with vertical sideslopes (although some moist granular
    soils will exhibit apparent cohesion and temporarily stand on a
    vertical slope), they cannot be molded when moist and crumble easily
    when dry.

c/ 1 tsf = 96 kPa

Table 3. Minimum Acceptable Stability Requirements for the
          Matrix Classification System

Soil Type	w_e lbf/ft^3[a/]	Steepest Slope hor:vert.
I	20	1/2:1
II	40	3/4:1
III	60	1:1
IV	80	1 1/2:1

Notes:

1. If there is any indication of general or local instability, slopes
    shall be cut back to a slope which is at least 1/4 hor.: 1 vert.

2. In layered soils stability requirements are set by the weakest
    layer.
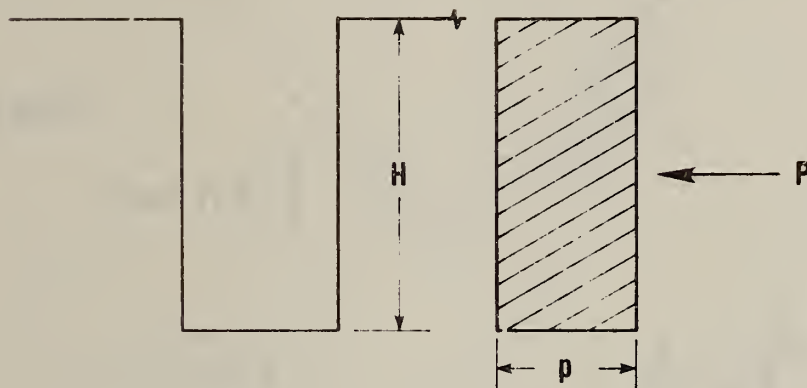
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a/ 1 lbf/ft^3 = 1.63 N/m^3

$p = w_e \ (H+2)$

$P = p \times H$

H = Height of supported bank, ft.
 (2 ft. are added to allow for surcharge)

p = Distributed horizontal earth pressure, lb/ft^2

P = Resultant horizontal force per unit length lb/ft.

w_e = Lateral weight effect, lb/ft^3

Note: 1m = 0.30 ft., 1 lb = 4.5 N, 1 lb/ft^2 = 48 Pa,
 1 lb/ft^3 = 157 N/m^3

Figure 1: Lateral Loads on Shoring Systems
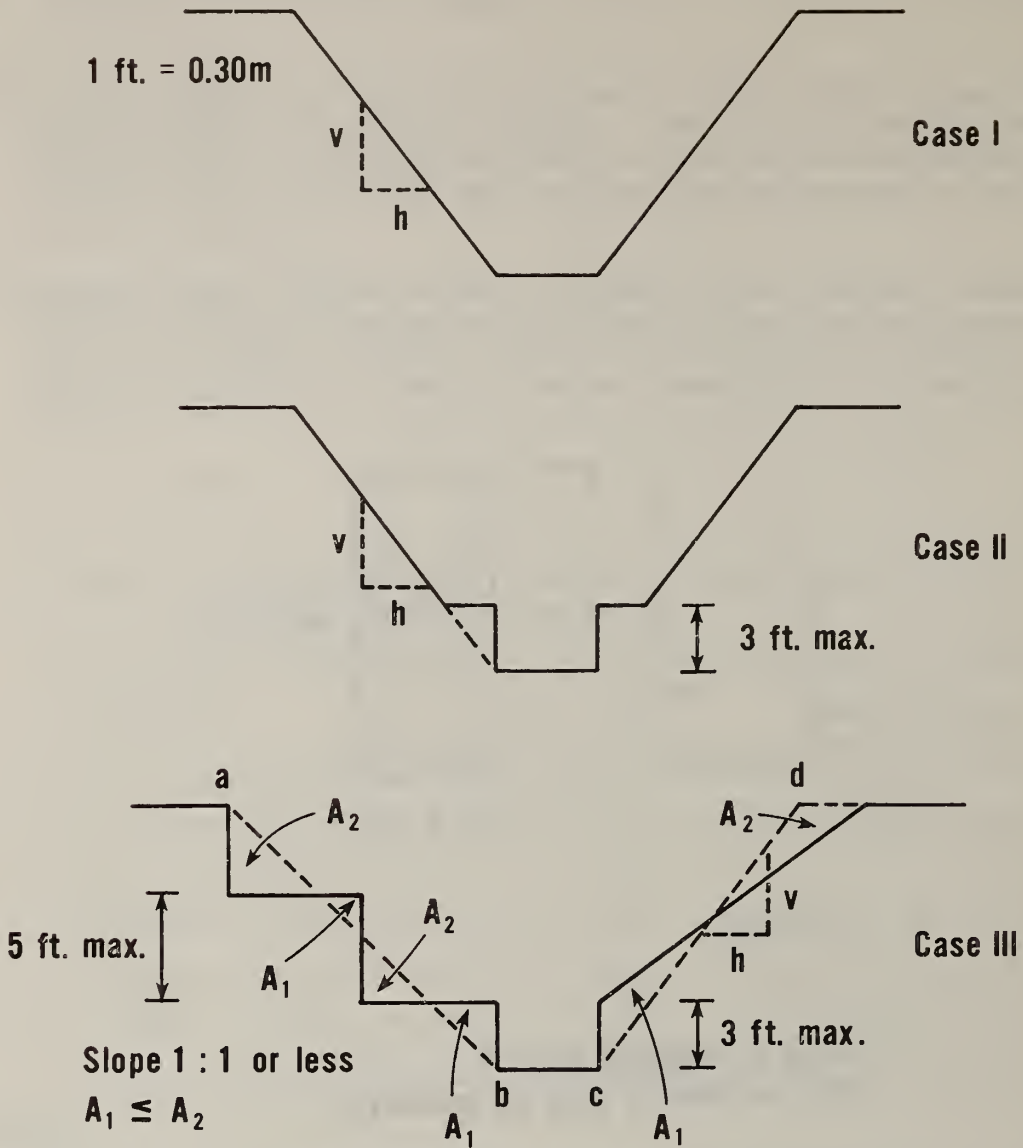
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$\dfrac{h}{V}$ = Steepest allowable sideslope

1 ft. = 0.30m

Case I

Case II

3 ft. max.

a

A_2

d

A_2

V

h

5 ft. max.

A_1

A_2

Case III

Slope 1 : 1 or less

$A_1 \leq A_2$

b   c

A_1

A_1

3 ft. max.

Case I - Ordinary slope

Case II - Compound slope with bench no more than 3 ft. high

Case III - Configuration must meet following criteria:

1. No vertical bank to exceed 5 ft., the bank adjacent to the work area not to exceed 3 ft.

2. Imaginary slopes ab and cd not to exceed max. allowable. If steps are used (left side of III) imaginary slope (ab) not to exceed 1 : 1

3. Excavated area equal to or greater than area within abcda

Figure 2:   Allowable Slope Configurations

1. INTRODUCTION

Each year more than 100 lives are lost in the U.S. and many more injuries
occur as a result of excavation cave-ins. Of these fatalities over 87
percent occur in trenches less than 20 ft. (6 m) deep [18]. The imple-
mentation of the Occupational Safety and Health Administration (OSHA)
regulations for Excavation, Trenching and Shoring [9] so far has had
no observable effect on the number of trench fatalities [19]. Part of
this lack of success is attributable to the difficulties encountered in
the interpretation and implementation of these regulations.

A field study conducted by the National Bureau of Standards [7] indicates
that one of the major complaints received from contractors is that the
soil classification in subpart P of the OSHA Regulations for Excavation,
Trenching and Shoring [9] is too vague and that numerous disagreements
between contractors and compliance officers arise over identification of

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soil types. Most contractors expressed willingness to cooperate with OSHA but were confused about the applicability of the present regulations, particularly those in Table P-1 of the regulations, to their particular construction sites [22].

Data on the correlation of various soil types with accident rates are difficult to obtain. A review of selected Occupational Safety and Health Review Commission cases [22] indicated that data concerning soil types were generally not recovered in the reports on fatal accidents. Thompson and Tannenbaum [18] conducted a survey of 86 newspapers in order to determine the soil types associated with trench and excavation cave-ins. The data indicate the following correlation between soil type and frequency of accidents.

Soil Type	No. of Accidents
Clay and/or Mud	32
Sand	21
Wet dirt (probably silty sand)	10
Sand, gravel and clay	8
Rock	7
Gravel	4
Sand and gravel	2

The source of these data raises some questions since soils were generally not identified by qualified persons; however, the report does provide an indication that there is a strong correlation between the soil type encountered and the risk of a fatal accident.

Utility contractors tend to be familiar with the soil conditions in their particular areas and frequently use generic names such as "Del Rio Clay," "Taylor Marl," etc. These generic descriptions cannot always be easily correlated with the soil categories used in the OSHA regulations. Thus, there is frequently no common language between the utility contractors and OSHA compliance officers.

The purpose of this report is to recommend soil classification systems which could adequately relate shoring and sloping requirements to the soil type encountered in the field, and which could provide a common language between contractors, engineers, and compliance officers. General background information is given in Section 2. Methods of soil classification and characterization and parameters affecting the safety of trenching operations are discussed in Sections 3 and 4. In Section 5 two alternate soil classification systems are recommended, and Section 6 is a commentary on the recommended soil classification systems. Detailed background information on trenching practices and accidents which was assembled in the Texas study [22] is provided in the Appendix.

FACING PAGE: Backhoe used to excavate sloped trench

2. BACKGROUND INFORMATION

2.1 GENERAL

A detailed summary of background information and its sources is given in
Appendix A to this report to enable the reader to familiarize himself
with the trench stability problem. Information pertinent to soil classi-
fication is summarized in this section. The information has been derived
from references 7, 12, 18, 19, 20 and 22.

2.2 TRENCHING CHARACTERISTICS AND PRACTICES

2.2.1 General

As noted in the introduction, most fatalities from cave-ins occur in
excavations less than 20 ft (6 m) deep. The majority of these accidents

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occur in utility trenches which are less than 12 ft (4 m) deep (mostly
sewer trenches). The information provided herein is therefore confined
to utility-trench excavations.

2.2.2 Contractor Characteristics

Utility contractors typically bid on projects within a 50 to 75 mile (80-
-120 km) radius from their home base. Their companies tend to be rela-
tively small and stable, and their crews, and particularly their foremen,
have typically many years of experience in trenching within their area.
The contractors tend to specialize in one type of trenching work and
their machinery and the experience of their crews are key factors in
their decision on the methods to be employed to obtain trench stability.

2.2.3 Characteristics of Trenching Operations

For all but very large diameter lines, pipe laying is a dynamic opera-
tion, moving at a rate of several hundred feet per day. Soil structure,
moisture content, and related factors therefore tend to change frequently
requiring rapid decisions on methods of sloping or shoring to cope with
these changing conditions. As a consequence most firms rely on their
job foremen and equipment operators for on-the-spot decisions on sloping
or shoring. Foremen normally have a thorough working knowledge of the
physical characteristics of soils in their area. Shoring methods tend
to be developed on the basis of this experience and shoring systems are
employed without detailed design and analysis.

Pipe laying and backfilling operations tend to follow closely behind the
trenching. As a result less than 100 ft (30 m) of trench are normally
open at any one time. The time elapsed between opening of a trench and
backfilling after completion of the pipe laying operation is on the aver-
age less than 2 hours and seldom exceeds one day. However, smaller
trenches, such as those for sewer connections to individual houses, are
sometimes open for longer periods, if the excavation and the pipe laying
are carried out by different contractors. A similar situation occurs
where two trenches intersect. In such locations backfilling may be
delayed until the lateral pipeline is connected.

2.2.4 Sloping

Sloping is the contractor's preferred method of trench stabilization,
since it reduces contruction material handling and provides the most
reliable personnel protection. Sloping is normally performed by
hydraulic backhoes. The choice of the angle at which banks are sloped
is usually at the discretion of the backhoe operator, who is rarely
aware of the exact slope angle required by the OSHA regulations [9],
but instead relies on his own experience and knowledge of the soil
conditions.

2.2.5 Shoring

Shoring is employed where sloping is not feasible or economical because
of right of way restrictions, adjacent structures or trench depth (slop-
ing is difficult and uneconomical for deep trenches). Sometimes the
bottom portion of a trench is shored and the upper part sloped. The
width of shored trenches seldom exceeds 6 ft (2 m). Details on shoring
systems presently used are provided in Appendix A.

2.2.6 Excavation Equipment

Backhoes are by far the most widely used and most versatile excavating
machines. They are suitable for vertical-side as well as sloped trenches
and permit the operator to deal conveniently with changing conditions.
In very regular trenches where there are no abrupt changes in sideslopes
or depth, wheel or ladder type trenching machines are used. These machines
are capable of relatively fast digging with accurate controls for the depth
and width of the excavation. In some instances, where the trench is deep
or the spoil pile is far from the trench, draglines are used.

2.3 Trench Cave-Ins

Correlations between soil conditions and trench cave-ins have been dis-
cussed in Section 1. The greatest safety hazards identified by contrac-
tors can be rank-ordered as follows: Disturbed soils (by previous
excavations, usually unknown to the contractor); intersecting trenches;
narrow right of way; vibrations (usually by construction equipment);
increased seepage of subsurface water; rainfall; drying of exposed
trench walls; and inclined layers of soil dipping into the trench.
Records also indicate that many accidents occur during installation and
removal of shoring. Sometimes cohesive soils which are disturbed or fis-
sured stand up long enough to permit workers to enter the trench but
subsequently collapse.

It is significant that the records indicate that most injured workers
were mature individuals. Thus, the number of accidents involving older,
and presumably more experienced, personnel tends to refute the argument
that experience is an adequate factor in judging trench wall stability.

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FACING PAGE: Spot bracing in dense clayey silt

3. SOIL CLASSIFICATION AND CHARACTERIZATION

3.1 <u>GENERAL</u>

A great number of soil classification systems have been introduced over the years to serve a variety of purposes. Many of these systems are still in use today. The type of system used in any particular instance usually depends on the soil properties that need to be characterized.

The soil properties that are presently most commonly described by classification systems are grain size distribution, plasticity, and organic content. These can be obtained from analysis of disturbed soil samples. Pedological classification systems used for agriculture generically describe the stratification and drainage characteristics of the upper soil horizons. Soil characterization for most engineering purposes

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needs to describe the undisturbed in-situ soil conditions such as density of granular soils or consistency of clays and is frequently provided as an addition to the soil classification by one of the conventional systems.

The Unified Soil Classification System ("Standard Method for Classification of Soils for Engineering Purposes," ASTM D2487-69) [2] has gained wide acceptance in the engineering community. For engineering purposes this classification is supplemented by information on density or consistency, or by direct measurements of the shear strength of the soil. In the Unified Classification System the soil classification is based on grain size distribution, plasticity (Atterberg Limits) and organic content. Soils are generally classified as "coarse-grained (sands and gravels)," "fine grained," or "organic". Fine grained soils are further classified into different types of silt and clay on the basis for their plasticity.

A less precise field identification system which is widely used for engineering purposes is the "Recommended Practice for a Visual Manual Procedure for Description of Soils," (ASTM D2488-69) [1]. The recommended practice is based on field identification by appearance and by simple tests which, although approximate in nature, provide a quantitative measure of the soil strength. Thus, this system provides a simple and approximate method of identification of those properties which need to be characterized for engineering purposes.

Table 3.1 compares various classification methods presently used in published standards for trenching. No quantitative values are given in the table. The coexistence of these classification methods causes considerable confusion and the terminology used is difficult to correlate with conventional classification techniques or accepted engineering practice.

3.2 SOIL PROPERTIES

Terzaghi and Peck [17] list 18 properties which should be determined to identify soils. These properties are shown in Table 3.2, together with checkmarks indicating which of the properties would be used to identify any one of 15 different soil types. However, not all the properties listed in Table 3.2 are identified in presently used classification systems.

Most classification systems, including the Unified Classification System [2], describe soils in terms of their particulate properties. The information gained from the tests associated with this type of classification is from disturbed samples and therefore can not completely describe the in-situ behavior of the undisturbed soil. The information does however provide a basis for determining whether a soil is granular (derives its strength primarily from intergranular friction, has little strength when soil is unloaded, strength increases rapidly when soil is

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Table 3.1 Soil Descriptions for Trenching

OSHA [9]		CAL OSHA [4]		Wisconsin OSHA [24]
Table P-1	Table P-2	Sect 1541	Appendix C	
Solid rock, shale or cemented sand and gravel	Hard, compact	Hard, compact	All soils except wet sands, saturated soil and soft plastic clays	Rock Hard, Solid
Compacted angular gravel				Soil that splits easily
Average soil	Likely to crack			Gravelly or filled in gravel
Compacted sharp sand		Unstable	Wet sands	Sand or very wet soil
Loose rounded sand	Soft, sandy, filled			
	Hydrostatic pressure	Running	Saturated soil soft and plastic clay	

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Table 3.2

Data Required for Soil Identification [17]

Type of Soil	General Information						Results Classification Tests — Intact Samples						Results Classification Tests — Disturbed Samples					
	Color	Odor	Texture	Dilatancy	Grain properties	Dry strength	Natural void ratio e	Natural water content w	Unit weight, natural state γ	Unit weight, oven-dried γ_d	Unconf. compressive strength q_u	Sensitivity S_t	Max. void ratio e_{max}	Min. void ratio e_{min}	Liquid limit L_w	Plastic limit P_w	Mechanical analysis	Carbonate content
Hardpan	X		X		X				X									
Sand, gravel	X				X		X						X	X			X	
Inorganic silt	X		X	X		X		X	X	X	X	X			X	X	X	X
Organic silt	X	X	X	X		X		X	X	X	X	X			X	X	X	X
Clay	X		X			X		X	X	X	X	X			X	X		X
Organic clay	X	X	X			X		X	X	X	X	X			X	X		X
Peat	X	X	X		X			X	X									
Till	X				X		X	X	X				X	X			X	
Tuff, fine-grained	X		X			X			X	X	X	X			X	X	X	
Loess	X		X	X		X	X	X	X	X	X	X	X	X	X	X	X	X
Modified loess	X		X	X		X	X	X	X	X	X	X	X	X	X	X	X	X
Adobe	X		X	X		X	X	X	X	X	X		X	X	X	X	X	X
Marl	X		X	X		X		X	X	X	X	X			X	X	X	X
Lake marl	X		X	X		X		X	X	X	X	X			X	X	X	X
Gumbo	X		X			X		X	X	X	X	X			X	X	X	X

loaded) or cohesive (derives its strength primarily from interparticle cohesion, has strength when unloaded, its strength changes slowly when it is loaded). The soil properties most often used in engineering design are those associated with strength, in-place unit weight, compressibility and permeability. Most of these properties can be correlated with the relative density of sands and the consistency of clays, and all the properties are related to the undisturbed (in-situ) condition of the soil. Their measurement is either performed by in-situ tests or by laboratory tests on undisturbed samples.

Since most conventional classification systems do not convey information on these properties, they have to be supplemented by additional information. It may be noteworthy to mention that when soil is used as a structural or borrow material (engineered fills) information on the particulate properties tends to be more important than information on in situ properties. In this case conventional classification systems are extremely useful. However this case is not germain to the excavation problem.

Typical values of strength properties and in-situ unit weight and their correlation with the relative density of sand or the consistency of clays and with widely used in-situ tests are given in Tables 3.3, 3.4 and 3.5. The following symbols are used in the tables:

$$D_r \quad = \text{relative density, percent} = \frac{\gamma_{dmax}}{\gamma_d} \cdot \frac{\gamma_d - \gamma_{dmin}}{\gamma_{dmax} - \gamma_{dmax}} \cdot 100$$

$$k_a \quad = \text{coefficient of active earth pressure} = \tan^2(45 - \frac{\phi}{2})$$

$\overline{N}$ = blowcount (per foot) in Standard Penetration Test [3]
ϕ = angle of shearing resistance, degrees
γ = in place unit weight, lb/ft^3
γ_d = dry unit weight, lb/ft^3
γ_{dmax} = maximum dry unit weight lb/ft^3
γ_{dmin} = minimum dry unit weight, lb/ft^3
γ_{sat} = unit weight of undisturbed soil in saturated state, lb/ft^3
γ_{sub} = in place bouyant unit weight, lb/ft^3 = $\gamma_{sat} - \gamma_w$
γ_w = unit weight of water, lb/ft^3

Table 3.3 shows approximate strength parameters for clays and their correlation with consistency and with two widely-used in situ tests: the thumb penetration test (ASTM D2488-69) [1] and the Standard Penetration Test (SPT) (ASTM D1586-67)[3]. The correlation between the $\overline{N}$-values of the Standard Penetration Test and the properties of clay should be regarded as no more than a crude approximation which is not always reliable. However the values for sands shown in table 3.4 are much more reliable and are frequently used for engineering design. This is particularly true since undisturbed samples of sand are difficult to take and the relative density (D_r) is a parameter which can not be easily

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Table 3.3. Properties of Cohesive Soil Correlated with Standard Penetration Test Results [6]

Clay Consistency	Identification (ASTM D2488-69)	SPT, $\overline{N}$ blows/ft	Undrained Shear Str. lbf/ft^2	Unconfined Compressive Strength lbf/ft^2
Very soft	Easily penetrated several inches by fist. Exudes between fingers when squeezed in hand.	<2	250	500
Soft	Easily penetrated several inches by thumb. Molded by light finger pressure.	2-4	250-500	500-1000
Medium	Can be penetrated several inches by thumb with moderate effort. Molded by strong finger pressure.	4-8	500-1000	1000-2000
Stiff	Readily indented by thumb but penetrated only with great effort.	8-15	1000-2000	2000-4000
Very stiff	Readily indented by thumb nail	15-30	2000-4000	4000-8000
Hard	Indented with difficulty by thumbnail	>30	>4000	>8000

Note: 1 ft = 0.30 m

1 lbf/ft^2 = 48 Pa

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Table 3.4 Relationship between Properties of Cohesionless Soil and Standard Penetration Test Results [21]

Soil Type	SPT, $\overline{N}$ blows/ft	Relative Density D_r%	ϕ (after Peck)	k_a
Very loose sand	<4	0-15	29°	>0.35
Loose sand	4-10	15-35	29-30°	0.35-0.33
Medium dense sand	10-30	35-65	30-36°	0.33-0.26
Dense sand	30-50	65-85	36-41°	0.26-0.21
Very dense sand	>50	85-100	>41°	<0.21

Approximate soil weights are given in Table 4.5.

Note: 1 ft = 0.30 m

Table 3.5 Typical Values of Soil Unit Weight [11]

Soil Type	Moist Unit Weight Above Water Table, γ(lb/ft^3)	Saturated Unit Weight Below Water Table γ_{sat}(lb/ft^3)
Poorly graded sand	105-115	115-125
Clean well graded sands	115-125	125-130
Silty or clayey sand & gravel	125-135	130-145
Soft to medium clay	100-115	100-115
Stiff to very stiff clay	110-125	110-125
Organic silt or clay	90-100	90-100

$\gamma_{sub} = \gamma_{sat} - \gamma_w$

$\gamma_w = 62.4$ lb/ft^3

Note: 1 lb/ft^3 = 16 kg/m^3

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measured in the laboratory. In the case of clay unconfined compression tests [ASTM D2166-66 (1972)] or other laboratory strength tests on undisturbed samples give reasonably good results, and simple in-situ tests such as cone penetration (ASTM D3441-75T) and vane shear tests (ASTM D2573-72) have been successfully used. It should be noted that the $\bar{N}$ values given in Tables 3.3 and 3.4 are representative of those obtained in traditional U.S. practice (rope and cathead). Adjustments should be made if other methods (such as trigger release hammers) are used. In Table 3.5 typical values for soil unit weight are given and correlated with various soil types.

3.3 SOIL CHARACTERIZATION IN CURRENT ENGINEERING PRACTICE IN TRENCHING AND EXCAVATION

3.3.1 General

The purpose of this discussion is not to provide a comprehensive review of current engineering practice and of available data, but rather to identify those soil properties which need to be quantified or defined if lateral soil pressures are to be calculated or slope stability determined in accordance with current engineering practice.

3.3.2 Soils Information Required in Current Engineering Practice

Figure 3.1 shows typical pressure diagrams extensively used in present U.S. engineering practice to calculate lateral loads on excavation bracing. Diagram (1) is for sands; Diagram (2) is for soft to medium clays; Diagram (3) is for stiff clays; and Diagram (4) is for dense cohesive (cemented) sands or for very stiff sandy clays for two different conditions which are specified in the figure. The symbols used in the figure are those previously used in tables 3.3-3.5. Additionally:

c = cohesion (cohesive strength)
H = depth of excavation
m = lateral force coefficient
N = "Stability number" = $\gamma H/c$

The diagrams in Figure 3.1 are widely accepted in current engineering practice; however, they are not the only pressure diagrams used. Other types of pressure distribution, such as those proposed by Tschebotarioff [21] also have gained wide acceptance. The following discussion of the soil properties that need to be defined in order to use the pressure diagrams in Figure 3.1 equally applies to these other approaches.

It is important to identify those soil properties which need to be quantified or defined in order to apply the pressure diagrams in Figure 3.1 to any specific case. These properties are shown in Table 3.6. The bracketed checkmarks are for properties which may have to be defined in order to identify the "soil type."

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1. Sands Ref [10]

**2. Soft to medium clays, when N > 6
(if pressures calclated under 3. using
0.4 γH are larger, use 3.)**

0.25H

0.75H

H

$\rightarrow$ 0.65 $k_a \gamma H$ $\leftarrow$

$k_a = \tan^2(45 - \phi/2)$

$\rightarrow$ 1.0 $k_a \gamma H$ $\leftarrow$
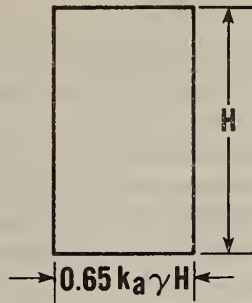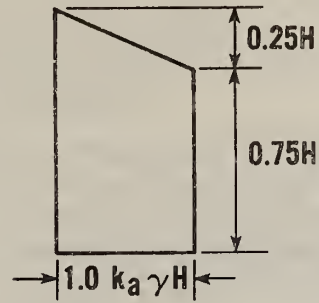
$N = \dfrac{\gamma H}{c}$ $\qquad k_a = 1 - m\dfrac{4}{N}$

When cut is underlain by deep, soft, normally
consolidated clays: m=0.4   All other cases: m=1.0

**3. Stiff clays, whenever N < 4. (if 4 < N < 6 use 2. or 3.,
whichever gives larger pressures)**

0.25H

0.50H

0.25H

0.2γH $\rightarrow$

$\leftarrow$ 0.4γH $\rightarrow$
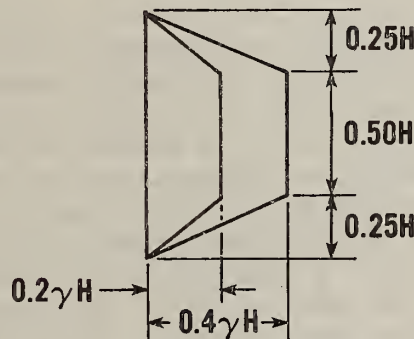
4. Dense cohesive sands, very stiff sandy clays *

Relatively uniform
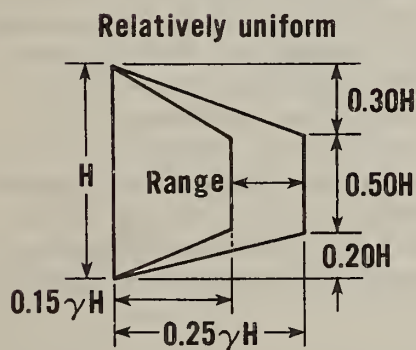
**Upper third of cut
dominated by cohesionless sands**

H   Range   0.30H

0.50H

0.20H

0.15γH

$\leftarrow$ 0.25γH $\rightarrow$

H   0.80H

0.20H

0.15γH

$\leftarrow$ 0.25γH $\rightarrow$
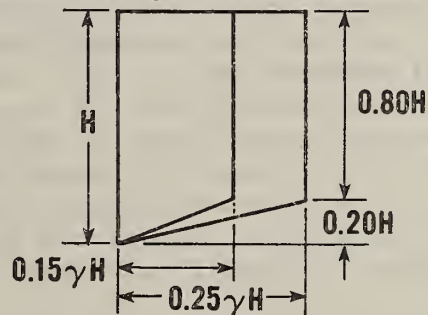
*Diagrams 1, 2, and 3 after Peck (1969)[10], Diagram 4 after Goldberg et.al.
(1976)[6]*

Figure 3.1: Lateral Soil Pressure Diagrams

Table 3.6. Soil Properties That Must Be Quantified
to Calculate Lateral Pressures

Property Soil Type	γ	ϕ	c
Sand	✓	✓	
Soft to Medium Clay	✓		✓
Stiff Clay	✓		(✓)
Dense Cohesive Sand	✓	(✓)	
Very Stiff Sandy Clays	✓		(✓)

Another engineering problem associated with trenching and excavations is
slope stability. The soil properties that need to be quantified in
order to determine slopes that will be stable without shoring are the
angle of shearing resistance, ϕ, for granular soils, and the cohesion, c,
the angle of shearing resistance, ϕ, and the in-place unit weight, γ,
for cohesive soils. Another important parameter in cohesive soils which
is not strictly a "soil property" is the depth to which tension cracks
(fissures) extend from the surface.

Certain soil properties must be defined or quantified in order to deter-
mine the "soil type" in Table 3.6. A determination must be made whether
the material is a "clay" or a "sand", or rather whether it should be
considered a cohesive material where the lateral forces are calculated
on the basis of the cohesion c, and ϕ is assumed to be small or negligible,
a non-cohesive material where c is assumed to be small or negligible and
the forces are calculated on the basis of ϕ alone, or a "cohesive sand"
or "sandy clay" where both, c and ϕ should be considered. If the
material is classified a "clay" a decision must be made whether it is
"soft or medium," "stiff", or "very stiff". This determination is based
on the value of the undrained shear strength (c) as shown in Table 3.3.

There are several methods by which the soil properties discussed above
can be determined. The value of ϕ in sands correlates with the "relative
density", D_r, a property which is not easily measurable in the laboratory.
It does however correlate reasonably well with a number of in situ mea-
surements such as the Standard Penetration Tests [3], cone penetration
tests and pressure meter tests. The angle of shearing resistance, ϕ,
could also be deduced from the observed angle of repose, (however, if
sands are moist, the angle of repose could be steeper because of apparent
cohesion), or it could be determined by laboratory tests, though it is
difficult to secure undisturbed samples of sands or otherwise reproduce
the in-situ density. Sowers and Sowers [15] proposed a manual procedure
to determine the density of sands.

Values of c for clays can be determined by a variety of methods. Two
methods, the thumb penetration test and the Standard Penetration Test
(SPT) are shown in Table 3.3; however the SPT is generally not recom-
mended for this purpose. Other in-situ methods include vane shear tests,
cone penetration tests and pocket penetrometer tests. Determination of

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c by laboratory tests on undisturbed samples such as the unconfined
compression test tend to be quite reliable.

In conclusion it should be noted that the important parameters associ-
ated with present engineering practice related to excavation are all
dependent on density or consistency. Neither of these parameters is
considered in the commonly used soil classification methods, with the
exception of the manual and visual procedures specified in ASTM D2488-69.

FACING PAGE: *Skeleton sheathing with prefabricated strut-wale assembly*

4. PARAMETERS AFFECTING TRENCH STABILITY

4.1 THE NATURE OF SHALLOW TRENCHES

In section 3.2 current engineering practice in calculating lateral soil
pressures and slope stability for excavations was discussed, together
with the soil properties that need to be determined in order to apply
this practice. The so-called "pressure envelopes" shown in Figure 3.1
were developed on the basis of measured data such as those in Reference
[5] which originated from deep excavations (deeper than 20 ft). Because
of the time element usually associated with such excavations, the data
are from excavations which were open for weeks or even several months.
There are fundamental differences between such excavations and typical
shallow utility trenches which are subsequently discussed.

(1) <u>Depth</u>

One of the effects of depth on the nature of the lateral-pressure envel-
ope is recognized in Figure 3.1. A dimensionless parameter, defined as
the "stability number" $N = \gamma H/c$ is introduced for cohesive soils. A
vertical cut can stand without external support when $N \leq 4$ or the depth
$H \leq 4c/\gamma$. Thus whenever the depth of the excavation is less than this
"critical" depth an arbitrary decision has to be made with respect to
the lateral forces that the bracing should be designed to resist, since
theoretically these forces are zero. This problem is recognized in
Figure 3.1 and guidance is provided in Figure 3.1 (3). For a stiff clay
c is from 1000 to 2000 psf (48-96 kPa). If we assume that the in-place
unit weight γ is between 100 and 150 lb/ft^3 (1600-3200kg/m^3) the corre-
sponding critical depth is 40-50 ft (12-15 m). For a very soft clay of
c = 250 psf (12 kPa) the critical depth would be about 10 ft (3m). Since
most utility trenches that need to be braced are sewers which tend to be
on the average 10 ft (3 m) deep, and most clays tend to have cohesive
strengths far in excess of 250 psf (12 kPa) it is evident that in the
majority of cases shallow trenches in cohesive soils can stand at least
temporarily without support. One conclusion that can be drawn from this
observation is that it will be extremely difficult to make meaningful
measurements of forces acting on shallow-excavation bracing in cohesive
soils. This is probably one of the reason for the absence of data. The
observation also casts some doubts on the relevance of present engineer-
ing practice in excavations to the special case of shallow trenches.

It is also important to recognize the effect of depth on soil character-
istics. Even in areas where soil conditions are relatively uniform, a
condition that is typical for many clay areas, the upper soil horizons
differ in character from deeper layers. There is the zone of active
plant life where organic materials accumulate and root systems break up
the soil structure. In addition, soil layers near the surface are subject
to oxidation, leaching, desiccation, frequent volume changes by alternate
wetting and drying and frost action, and to many other disturbances.
Thus cohesive soils near the surface tend to be disturbed by fissures
and tension cracks. Desiccated and fissured stiff or medium clays may
not have any cohesion left and therefore could act like a granular soil.
In some instances surface water penetrates into tension cracks in other-
wise intact clays and causes sudden increases in lateral pressures. The
effect of this disturbed zone may not be very significant in a deep
excavation where it constitutes a relatively small portion of the overall
depth, but it may dominate the behavior of a shallow trench. Frequently,
when engineering soil properties are determined by in situ tests or labor-
atory tests on volumetric samples, the test results will not reflect
the effects of structural disturbances such as tension cracks which have
a dominant influence on the magnitude of lateral forces.

(2) <u>Time</u>

It has already been noted that the measurements on which Figure 3.1 is
based were taken in excavations which were open for a long period of

time. On the other hand the typical utility trench is open for less
than two hours. In many instances, even if a condition exists that would
lead to failure in a long term excavation, the failure in a short term
excavation will not develop before the backfill is placed. This is true
for clays as well as sands. Moist sands frequently have cohesive
strength (apparent cohesion). Under these conditions excavations will
be temporarily stable with sideslopes that would slump with a change
in moisture content (either dryer or wetter conditions) and the forces
exerted on excavation bracing are also smaller in the short term. This
transient condition can not be relied on in engineering practice, but
it plays an important role in construction.

(3) Excavation Methods

It has been shown [16] that the distribution of soil pressures on retain-
ing structures is influenced by the deformations and displacements that
the retaining structure will undergo after the load is applied and by
the restraints on the deformation of the retained soil mass. Thus the
pressure distribution against a rigid retaining wall tends to be trian-
gular when the top of the wall is allowed to rotate away from the
retained soil and parabolic if the bottom rotates out. The magnitude
of the pressures corresponds to the active pressure if the retained soil
mass is allowed to expand out sufficiently, the passive pressure if the
wall is pushed toward the soil mass to the verge of failure and the
prevailing in-situ pressure if no movement is allowed to occur. Thus
the pressure diagrams shown in figure 3.1 are not independent of the
displacements that occurred in the soil mass during excavation and the
magnitude of the preloading forces on the struts.

In present deep-excavation practice the struts (cross braces) are placed
and preloaded while the excavation is in progress. This effectively
restrains the displacements near the top of the excavation. As the exca-
vation progresses downward significant inward displacements do occur near
and below the bottom of the excavation [8] but they are restrained as
each successive tier of cross braces is placed and preloaded. On the
other hand shallow trenches are typically excavated to their full depth
before cross braces are placed. This may cause lateral pressures to
decrease in many instances; however in some other instances it may pro-
mote the development of fissures. In some types of shallow trench brac-
ing, such as trench boxes, the protective sheeting may actually exert
no thrust on the side of the excavation, and in many cases a void remains
between the side of the excavated trench and the sheeting. In this
instance pressure will only be exerted if the sides of the excavation
move in as a result of deformation, a general shear failure, or the
localized separation of some volume of soil.

Thus, it is reasonable to assume that the magnitude and distribution of
soil pressure on shallow-trench bracing may significantly differ from
that shown in Figure 3.1.

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4.2 PARAMETERS AFFECTING THE STABILITY OF SHALLOWS TRENCHES

4.2.1 General

In Section 3 the soil properties which must be identified in present engineering practice are discussed. The subsequent discussion in 4.1 draws a distinction between deep excavations and shallow trenches, and identifies some other parameters which affect the behavior of shallow trenches. It is convenient to divide the parameters which affect the behavior of shallow trenches into three categories.

1. The primary soil properties which generally characterize the soils as seen at a point within the soil mass or within a small volumetric element that is tested in the laboratory.

2. The secondary soil structure which characterizes the soil or rock mass adjacent to the excavation or rather that part of the soil mass which could affect the stability of the trench.

3. Site and working conditions which affect trench stability.

Primary soil properties are discussed in Section 3. Some of the important effects of secondary soil structure are discussed in Section 4.1. Other effects of the secondary soil structure as well as site and working conditions are discussed hereafter.

4.2.2 Secondary Soil Structure

(1) Discontinuities

Discontinuities are sometimes of a magnitude which escapes visual identification and may cause planes of weakness in a soil mass which are not detected in laboratory sized samples. This is perhaps best illustrated by an example from Reference [22]. A severely jointed clay with slickensides in Houston, Texas was classified as a highly plastic clay (CH) in accordance with the Unified Soil Classification System (ASTM D2487-69). Undisturbed samples taken at their natural water content in the in-situ condition before soil disturbance by excavation had an unconfined compressive strength of 4 tons/ft^2 (383 kPa). Observations indicate that when trenches are excavated this soil becomes unstable and fissured. Laboratory and field investigation of the soil in its fissured condition showed that the cohesion approaches zero. This clay would eventually behave like a granular soil [14]. The development of fissures is particularly pronounced when the soil is allowed to expand laterally and when changes in water content weaken its shear strength.

Another type of discontinuity causes problems in rock excavations. The bonding between bedding planes or across other discontinuities is sometimes very weak or non-existent due to erosion or presence of weak materials such as micaceous layers or clay seams. When these planes slope toward the side of an excavation the shear stresses in the direc-

tion of the discontinuity may exceed the shear resistance provided by friction and bond. The situation is sometimes aggravated by excess pore water pressure and by the lubricating effects of seepage, micaceous materials and clay seams. The danger is particularly great when the excavation is classified as a rock excavation and therefore not braced.
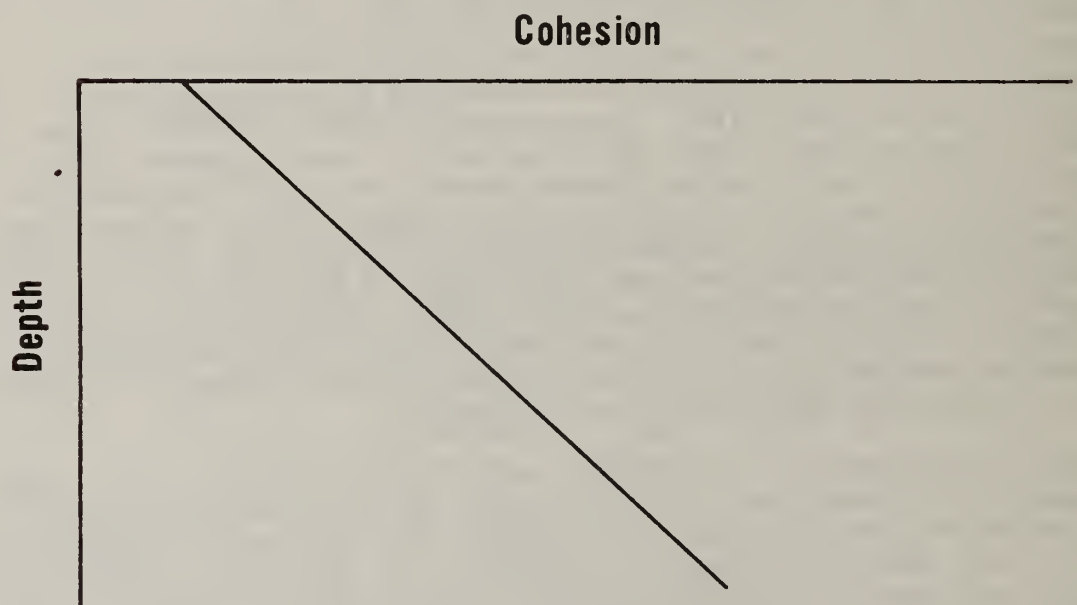
(2) Overconsolidation

Soils which have been subjected to loads greater than those presently exerted by the overburden are overconsolidated. Overconsolidation can be caused by glaciation (weight of ice), tectonic movements, erosion, desiccation and other effects. Most surface deposits of clay are overconsolidated by desiccation [13]. The potential effect of this overconsolidation on the relationship between shear strength and depth is shown in Figures 4.1(a) and (b) which show frequently observed profiles of cohesive strength versus depth for overconsolidated and normally consolidated clays, respectively (clays are normally consolidated when present vertical pressures were not exceeded in the past). Note that in Figure 4.1(b) the cohesive strength decreases with depth up to a certain depth. If a trench is excavated under these conditions the bottom of the trench, where the soil is subjected to the greatest shear stresses, may be located in the region of least shear strength. The soil conditions shown in Figure 4.1(b) may also lead to erroneous conclusions with respect to the critical height at which an unsupported vertical slope will stand without collapsing.

Overconsolidated clays frequently exhibit high in-situ permeability. An example of this condition was encountered in an area about 45 miles northeast of Austin, Texas [22]. An undisturbed sample resembled canned solid white tuna in that it broke and crumbled in a similar manner. Water placed on the sample quickly passed through the clay. An unconfined compression test at the natural moisture content showed an unconfined compressive strength in excess of 3 tons/ft^2 (287 kPa). However when additional water was added the sample began to disintegrate. The sample taken in this instance was highly fissured. However other available evidence indicates that water may rapidly flow through apparently unfissured samples as well, and an increase in water content will result in a significant decrease in shear strength.

Since overconsolidation of surface deposits of clays is a common phenomenon, an allowance for this possibility should be made when soils are classified for the purpose of trenching. The limitation of unbraced cuts to a five foot (1.5 m) depth is reasonable for most conditions; however in some instances precautions against sudden collapse caused by water penetration may be necessary even for very shallow depths.

23
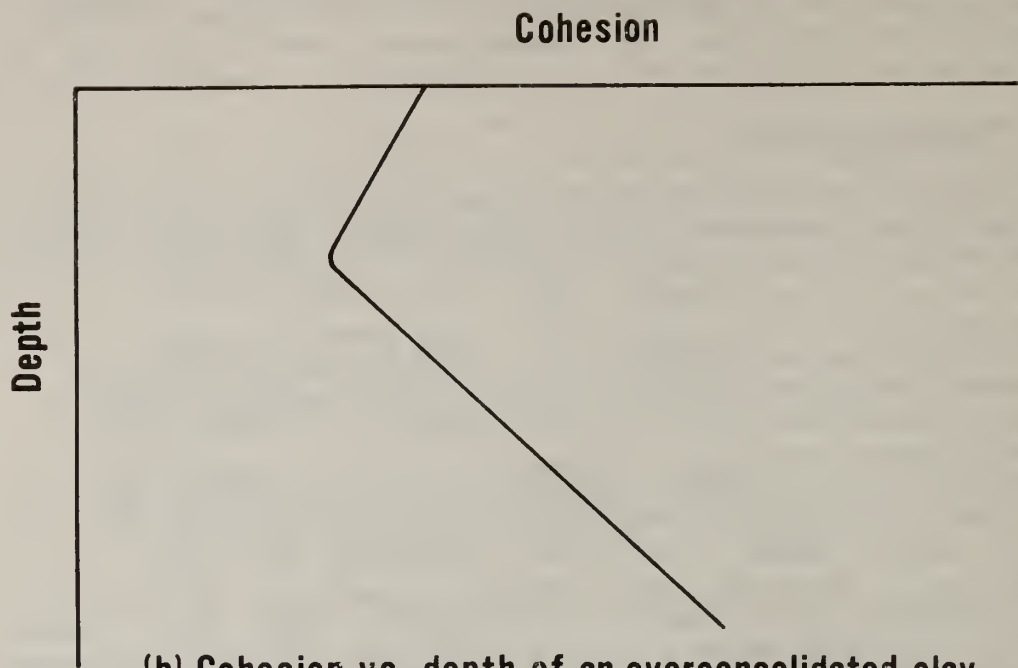
Cohesion

Depth

(b) Cohesion vs. depth of an overconsolidated clay

Cohesion

Depth

(a) Cohesion vs. depth of a normally consolidated clay

Figure 4.1:   Profiles of Cohesive Strength vs. Depth in Normally
Consolated and Overconsolidated Clays

4.2.3 Site and Working Conditions

(1) Water

The effect of a change in the water content on the strength of soils
was discussed in previous sections of this report. If a trench fills
with water, or if heavy rain and flooding occur, the water content of
the surrounding soil will in most instances increase. As previously
noted, such an increase in water content will weaken most soils. However
in medium to fine poorly graded sands, an increase in moisture content
may increase the shear strength due to tensile forces induced by capil-
lary suction (apparent cohesion). This strength increase disappears
if the moisture content is either decreased or increased from a certain
optimum. One contractor interviewed [22] claimed to have deliberately
flooded sandy areas so he could excavate with steeper sideslopes.

Most major problems associated with water are caused by occasional flood-
ing by rain, water line breaks and snow or ice melts. While a trench
is filled with water the stability of the sideslopes may actually in-
crease in most instances since the soil is submerged and its weight
decreases and excess pore pressures tend to equalize. Since flooding
of trenches inhibits the construction work, contractors pump the water
and drain the trench as rapidly as possible. As the pumping proceeds,
seepage forces develop and a significant amount of finer particles drains
from the trench walls into the trench and is pumped out with the water.
This will cause an increase in the void ratio of the soil adjacent to
the trench and thus reduce the shear strength [26]. However rapid pump-
ing may have other more serious effects. As a result of the rapid draw-
down the trench could be almost empty while the surrounding soil is fully
saturated. This increases the unit weight of the soil and thus the
driving forces which can cause a stability failure while at the same
time the shear strength is reduced by saturation and excess pore water
pressures. As a consequence the trench may collapse during or shortly
after the pumping operation. The severity of these effects depends to
a large degree on the drainage and strength characteristics of the sur-
rounding soil. Not much data are available on this phenomenon [23].

Current OSHA regulations specify that trenches must be inspected after
rains. This provision may not be adequate. If the soil adjacent to a
trench has undergone radical changes in moisture content the stability
of the trench may be in question. Additional shoring or flatter slopes
should be considered if the construction is in a location or season
where flooding or severe rain could be anticipated.

(2) Desiccation

Desiccation (drying) of the trench wall or bottom could cause difficult
problems; however these problems are more significant in excavations
that are open for long periods of time. As previously noted desiccation
causes tension cracks and overconsolidation in the soil layers near the
surface. Desiccation occurs as a result of exposure of soils on the

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side and bottom of an excavation to air. When the moisture content of clays decreases the volume of the clays decreases. The shrinkage causes tensile stresses in intact clays which result in tensile cracks whenever the tensile strength is exceeded and in fissured clays it causes existing fissures to open up. Eventually the tensile strength can completely dissappear and the material acts like a granular soil. However, unlike sands, these desiccated clays may lose much of their shear strength when water penetrates the fissures. Typical desiccation effects which were observed in Houston [22] are shown in Figure 4.2. The failure wedge abc in Figure 4.2(a) is probably attributable to desiccation near the surface which existed prior to opening of the trench. The spalling of column a, a', b, c is attributable to desiccation on the side of the excavation after opening of the trench.

Drying of moist sands may have adverse effects in sloped excavation where the angle of slope depended on apparent cohesion.

(3) Previous Disturbances

Previous disturbances are most frequently observed at utility line crossings. There is evidence from field studies by NBS [7] that contractors are frequently unaware of the presence of previously disturbed areas and accidents result as a consequence. The most dangerous situations occur in excavations in cohesive (hard, compact) soils where skip bracing rather than tight sheeting is used. The decrease in cohesive strength is not always noticed during the excavation stage and subsequently the trench may collapse during or after insertion of the bracing. It should be noted that in most instances backfill in utility trenches is not compacted and thus previously disturbed material tends to be much weaker than the surrounding soil.

(4) Vibrations

Vibrations are caused by excavating equipment, driving of piles and sheet piles, traffic, and operations in the trench itself. In saturated sands or silts vibrations could cause substantial or complete loss of shear strength (liquefaction), causing the soil to act like a liquid and substantially increasing lateral pressures. Loss of shear strength could also occur in sensitive clays. In addition, the dynamic forces caused by vibrations could temporarily increase lateral pressures. The most dangerous potential consequence of vibrations on braced excavations is their possible effect on the bracing itself. Struts are wedged against the walls or uprights and exert lateral pressures against the trench wall. Frequently it is this lateral pressure which keeps the struts in place and no tie is provided. Vibrations can cause relative movement between bracing elements which may result in a reduction or release of these pressures causing the unloaded struts to separate and fall off. This loss of support can trigger a collapse. Another consequence of loss of, or reduction in, the preload of struts could be that the retained soil may become disturbed.

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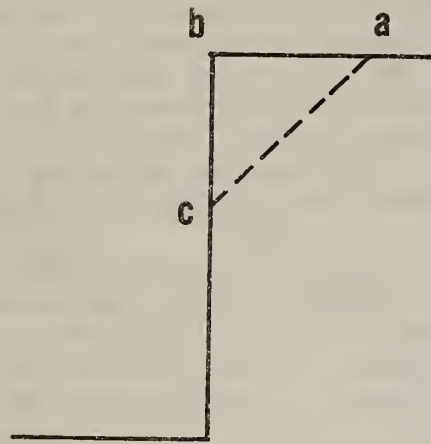
(a) Effect of initially desiccated zone
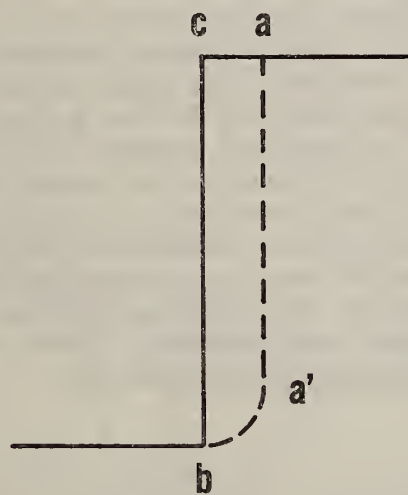
(b) Desiccated pillar mode of failure

Figure 4.2: Desiccation Effects Observed in Cuts in Clays

(5) Surcharge

Surcharge imposes additional lateral forces on trench bracing and
increases the driving forces which could cause a stability failure of
a sloped excavation. Surcharge loads are exerted by spoil piles, excava-
tion equipment and stored building material, and sometimes by building
foundations which are close to the trench. As a rule of thumb, any load
which is located within the area where imaginary 45 degree sideslopes
intersect the ground surface has an effect on the stability of the exca-
vation. This rule of thumb, however, may not be conservative enough for
very soft or loose soils. A sideslope ascending from the edge of a
vertical braced excavation also acts like a surcharge.

Present OSHA regulations require that spoil piles be kept two feet from
the edge of the excavation slope. While this provision alleviates sur-
charge effects it does not eliminate these effects and it is primarily
intended to reduce the danger of spoil material spilling, or objects
rolling into a braced excavation, or sloughing of the upper corner of
sloped excavations. There should be similar provisions for excavating
and construction equipment and machinery.

(5) Trench Discontinuities

Field studies conducted by NBS [7] indicate that many accidents occur at
trench discontinuities, particularly at intersections between two
trenches which occur whenever lateral pipes are connected to sewer
trunklines. Discontinuities also occur at manhole locations or when
a trench changes direction. One potential effect is shown in a simpli-
fied way in Figure 4.3. The shear strength of the soil required to
resist a slide along planes outlined by the dotted lines in Figure
4.3(a) is less than that required to prevent the failure at the corner
shown in 4.3(b). Note that frequently at trench intersections only
the main trench is braced while the lateral trench is still unbraced,
particularly since installation of trunklines and lateral lines is often
done by different contractors and at different times. If this situation
arises, the thrust exerted by preloaded struts can cause a failure
of the corner at the trench intersection. There are presently no OSHA
provision to prevent this dangerous situation.

(6) Time

Effects of time were discussed in Section 4.1. Time effects include:
desiccation of clays; loss of shear strength in overconsolidated clays
after lateral expansion; loss of apparent cohesion in sands; weakening
of bedding planes of rock by seepage; and erosion. Some failures in
a soil mass do not occur suddenly but rather manifest themselves by
slow movements over considerable periods of time. This includes stab-
ility failures in cohesive soils. In many instances the time element
required for a failure to develop is much longer than the time typical
utility trenches are left open (two hours or less).
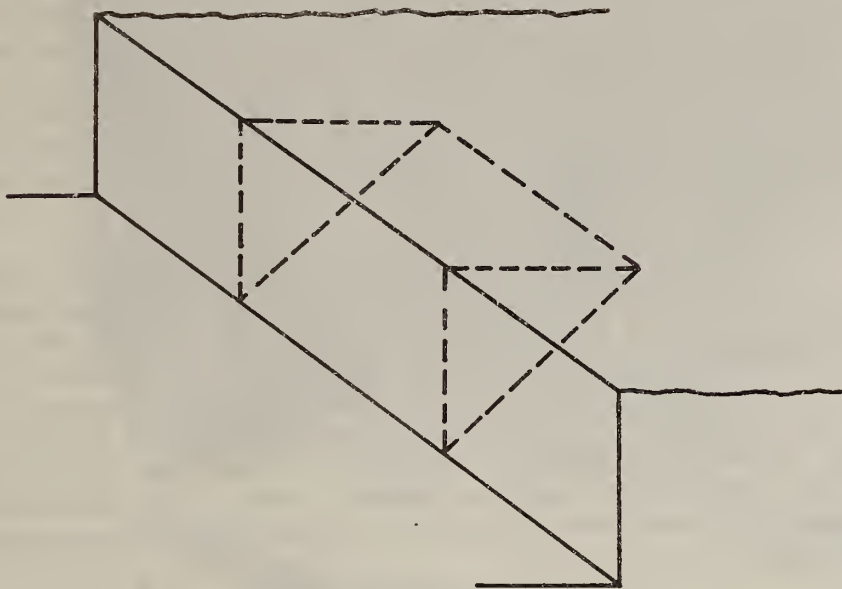
(a) Potential failure section of straight trench
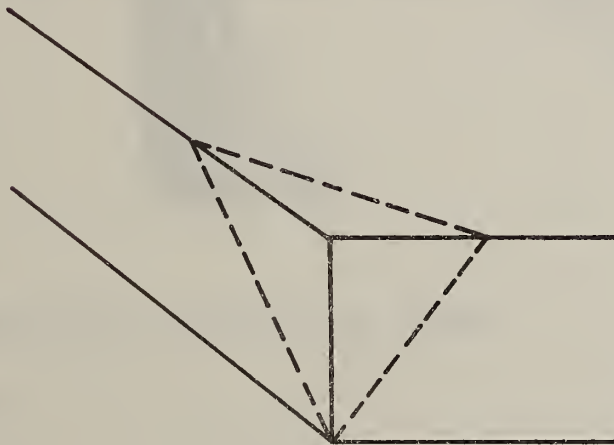
(b) Potential failure section at corner

Figure 4.3:   Effect of Trench Intersection on
Sideslope Stability

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There is also a complex relationship between drainage conditions and time. The "undrained" condition is usually more critical since the effective shear strength is less under undrained conditions when effective normal stresses are reduced by excess pore water pressure. In utility trenches the undrained condition usually governs. In larger excavations both drained and undrained conditions may have to be considered, except when the excavation proceeds at a slow enough pace to permit drainage while the work is in progress. In cohesive soils it is customary to rely only on the part of the shear strength attributable to cohesion when undrained conditions are anticipated. Cohesion, in turn, can be determined in an unconfined compression test.

Time effects can be critical in overconsolidated clays. The following observation illustrates one instance where reduced confining pressures caused a failure [22]. A vertical 8-ft (2.4-m) deep trench was opened in a fissured clay in Houston, Texas to observe its behavior. Initially the soil appeared stable with no visual indication of fissures. Skeleton braces were installed 8 ft (2.4 m) on center. After 45 minutes several sections between the uprights suddenly collapsed. This is a typical situation which can lead to fatal accidents, since there is sufficient time for workers to enter the trench, but instability occurs before the work is completed.

Unfortunately time effects on trench stability are difficult to quantify and no recorded data are available. To the extent that accident reports are available they seldom describe the events adequately or contain an accurate chronology of events. However there are indications that trenches left open for a few hours behave differently from those open for a few minutes, and that long term excavations generally require stronger bracing or flatter sideslopes than short term utility trenches.

FACING PAGE: *Compound slope used in large irrigation project*

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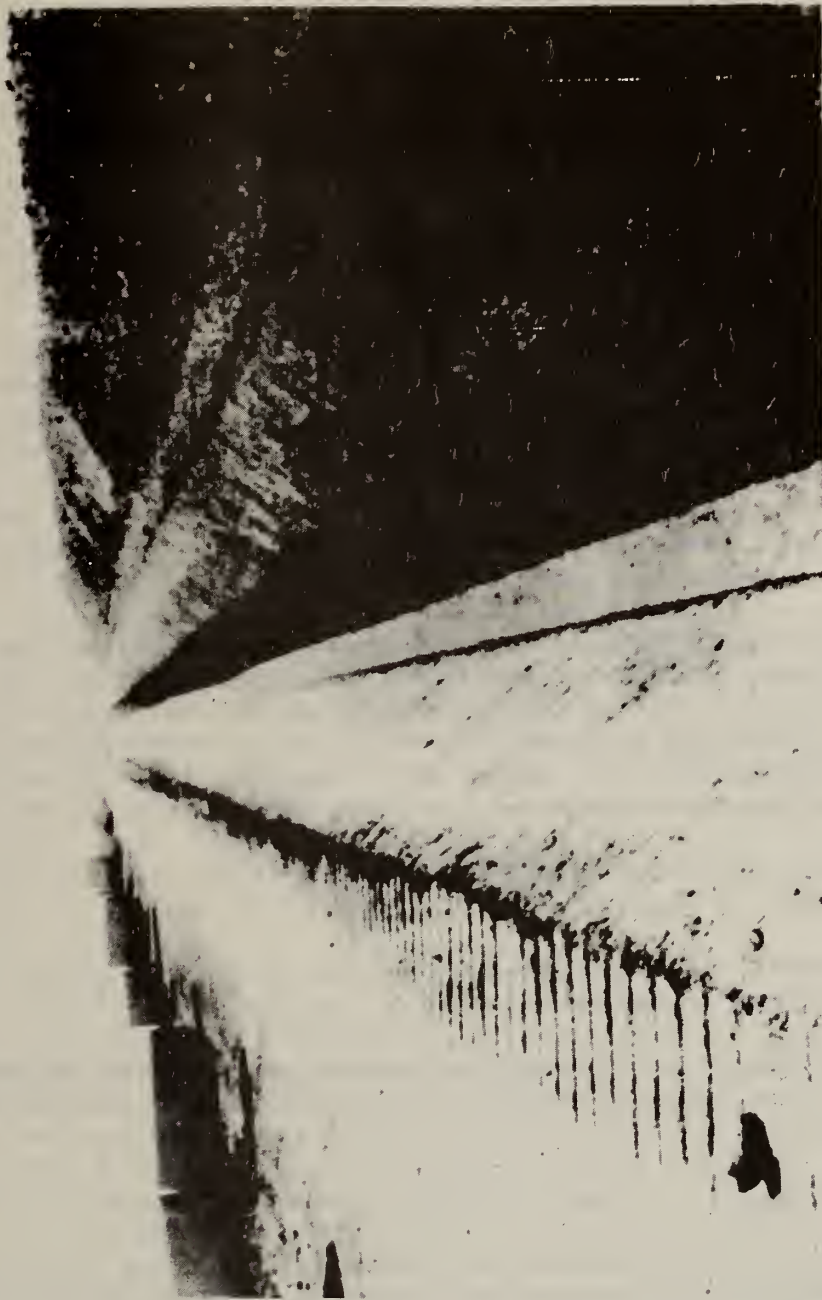
5. RECOMMENDED SOIL CLASSIFICATION SYSTEMS

5.1 GENERAL

5.1.1 Purpose

Any recommended soil classification system must be designed to serve the purpose of its intended use. Thus, it is important to determine who will use it and how it is to be used.

Engineers generally follow the practice outlined in Chapter 3, which relies on the determination of in situ soil properties. Additionally, engineers consider many other parameters such as ground and surface water, drainage characteristics, tension cracks, and static and dynamic surcharge loads. Since each location has its own problems, and engineers are trained and qualified to deal with these problems in accordance with

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the state of the art, a formal soil classification system to supplement engineering practice in excavations would not necessarily serve a useful purpose and could even be harmful by narrowing the range of options available to engineers. Thus, the recommended systems are not intended to supplement present engineering practice.

A different situation arises when pre-fabricated systems and devices such as trench boxes or hydraulic shores are used. In this instance it is necessary to determine in advance under which field conditions the systems can be used. This is best accomplished by a classification system which categorizes anticipated field conditions and gives adequate consideration to the critical parameters. The role of the engineer would then be to determine whether the shoring system is adequate for its intended use.

In shallow utility trenches where work proceeds at a fast pace and soil conditions tend to change rapidly it is generally not realistic for an engineer to design shoring systems or determine slope stability while the work is in progress. For this case a classification system is needed which allows the rapid identification of field conditions by both construction supervisory personnel and OSHA inspectors.

Thus, the classification systems recommended herein are intended to serve two purposes:

1. to predetermine conditions for the use of pre-fabricated or pre-designed shoring systems

2. to allow rapid determination of shoring and sloping requirements for various field conditions by construction supervisors and OSHA inspectors.

5.1.2 Criteria

On the basis of the discussion in Sections 3 and 4 and the results of the field studies discussed in this report, the following principles were derived for creating a soil classification system:

1. The system must be comprehensive (not exclude any condition that could be encountered, except for extreme or unusual cases which require supervision by an engineer).

2. All the critical parameters must be considered, either implicitly or explicitly.

3. Ambiguity must be avoided (any two persons classifying a site should arrive at the same conclusion) and in case of a dispute it should be possible to make objective determinations.

4. The system must be simple enough to be useable by construction supervisory personnel and by OSHA inspectors.

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Note that Criterion (3) is difficult to meet. Soil is a natural material and no two locations are exactly alike. Thus, a precise definition that does not require subjective judgment can only be based on the most obvious and easy to recognize soil properties. Such an approach is by necessity conservative, since it must satisfy the worst condition out of the range of possible conditions within a given soil class.

Criterion (4) also poses problems since supervisory personnel and inspectors are neither trained in geotechnical engineering, nor do they have the means to perform any but the most primitive tests. More accurate laboratory tests will in most instances only be used to resolve disputes.

5.1.3 Existing Classification Systems for Trenching

Some of the present soil classification systems devised for trenching are shown in Table 3.1. An attempt is made in the table to correlate the soil descriptions by their position on a vertical scale which goes from "strong" (rock) to "weak" (soft clay). Note that OSHA as well as CAL OSHA have dual systems (Table P-1 vs. Table P-2, Section 1541 vs. Appendix C) which cannot be easily correlated with each other. In accordance with the NBS field study [7] the systems in CAL OSHA Appendix C and Wisconsin OSHA are both successfully used and generally acceptable to their users.

It is useful to examine the compliance of the systems in Table 3.1 with the criteria in 5.1.2:

> OSHA Table P-1 does not meet Criterion (1) except if everything that is not defined is considered an "average soil" (this would include everything from hard to soft clay). It does not meet Criterion (2) very well, though it may be argued that many parameters are considered implicitly. It does not meet Criterion (3) since even a qualified soils laboratory could not determine when a sand is "sharp and compacted" and a gravel is "angular". For the same reason the system can also not be considered simple.

> OSHA Table P-2 meets Criterion (1) since any conditions could be placed into one of the categories (this pre-supposes that the comma in one instance stands for "and", in the other for "or"); it meets Criterion (2) implicitly, even though hydrostatic pressure inadequately describes potential water effects; it does not adequately meet Criterion (3), even though it could meet the criterion if certain definitions were added for "hard", "likely to crack," and "soft", and it reasonably meets Criterion (4).

> CAL OSHA, Section 1541 could meet Criterion (1) with additional definitions, it implicitly meets Criterion (2); it would need some added definitions to meet Criterion (3); and it meets Criterion (4).

CAL OSHA, Appendix C meets Criteria (1), (3), and (4) but does not completely meet Criterion (2) since it does not consider surcharge effects.

Wisconsin OSHA does not meet Criterion (1) since it would be difficult to know where to fit soft clay; it probably meets Criterion (2) implicitly; it would need added definitions to meet Criterion (3); and it meets Criterion (4).

Two questions arise in conjunction with these existing systems:

1. Is compliance with all four criteria proof that a system is sound? The answer to this question is that compliance with the criteria is a necessary (or at least highly desirable) but not a sufficient condition. In additon to compliance with the criteria, a system should lead to technically sound and safe decisions (though this could be the case if Criterion 2 is adequately satisfied) and should provide enough options to the contractor. Thus, even if soil categories are clearly defined, the choice of these categories and the lateral forces or slopes assigned to them may not be sound. This could lead to a situation where it would be easy for a contractor to determine a soil type and there would not be many disputes between inspectors and contractors, but the accident rate would be high because of inadequate shoring, or shoring cost would be exorbitant because of excessive safety margins.

2. If a system does not fully meet all four criteria, can it still be used? Experience indicates that the answer to this question is yes. The two cases in point are the CAL OSHA, Appendix C system and the Wisconsin system.

   The CAL OSHA, Appendix C system is slightly deficient by not considering surcharge. It also assigns rather small lateral forces to soils which are not wet sands, saturated, or soft clays. One reason for the success of the system may be that its use is confined to a limited geographical area. If the system were to be adopted nationwide, extensive use of very small lateral pressures may have adverse consequences. Similarly, if the Wisconsin sytem were used nationwide, it may lead to difficulties in soft clay areas.

5.2 RECOMMENDED SYSTEMS

5.2.1 General

Before a classification system is adopted, a decision must be made about its degree of sophistication. The adoption of a system which is very simple and uses few easily recognizable soil categories is likely to reduce judgment errors by construction personnel, simplify enforcement and prevent costly litigation. On the other hand, it is likely to decrease the number of the contractor's options and thereby in some instances increase construction costs. A more sophisticated system

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would require better training of construction personnel and inspectors and may increase the chances for errors, but if skillfully used it could result in more economical and in some instances safer construction. Accordingly, two alternate systems are recommended. A "simplified" classification system, and a more sophisticated "matrix" classification system. Before a decision is made which of the two systems should be adopted, the advantages of each system must be weighed against its disadvantages. It is not recommended that both systems be adopted.

5.2.2 Definition of Lateral Pressures and Allowable Sideslopes Associated with the Classification Systems

The choice of a soil class or category determines allowable sideslopes in sloped excavations and lateral pressures that shoring must be designed to resist. These are explained hereafter.

Figure 5.1 shows allowable sideslopes. The steepest allowable sideslope is specified as the ratio of horizontal over vertical (h/v) for each soil category. Cases I, II and III in the figure show sloped-excavation configurations that should be permitted to provide some flexibility to contractors.

Figure 5.2 shows the lateral pressure diagram assumed to act on the excavation bracing. The bracing should be designed to resist these lateral pressures with suitable safety margins.[3] The equivalent uniform pressure w_e is specified for each soil category. Note that unlike some of the pressure diagrams used in present engineering practice (figure 3.1) a simple rectangular pressure diagram is used for all soil types. A more complex diagram would not be justified because of the approximate nature of this approach. An additional 2 ft (0.6 m) are added to the depth [H] for the purpose of calculating pressure in order to allow for surcharge loads. It is recommended to use 100 percent of the calculated load for the design of struts (cross braces), 80 percent for the design of wales, and 67 percent for the design of sheeting.

5.2.3 Simplified Classification System

This recommended system is similar to the one used in CAL OSHA Appendix C; however, it differs in one important aspect: the category

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[3]Specification of safety margins is not within the scope of this report, but as a general philosophy it is envisioned that allowable working stresses permitted in present engineering practice should not be exceeded in long-term excavations and could be exceeded by up to 33 percent in excavations open for less than 24 hours.

$\dfrac{h}{v}$ = Steepest allowable sideslope
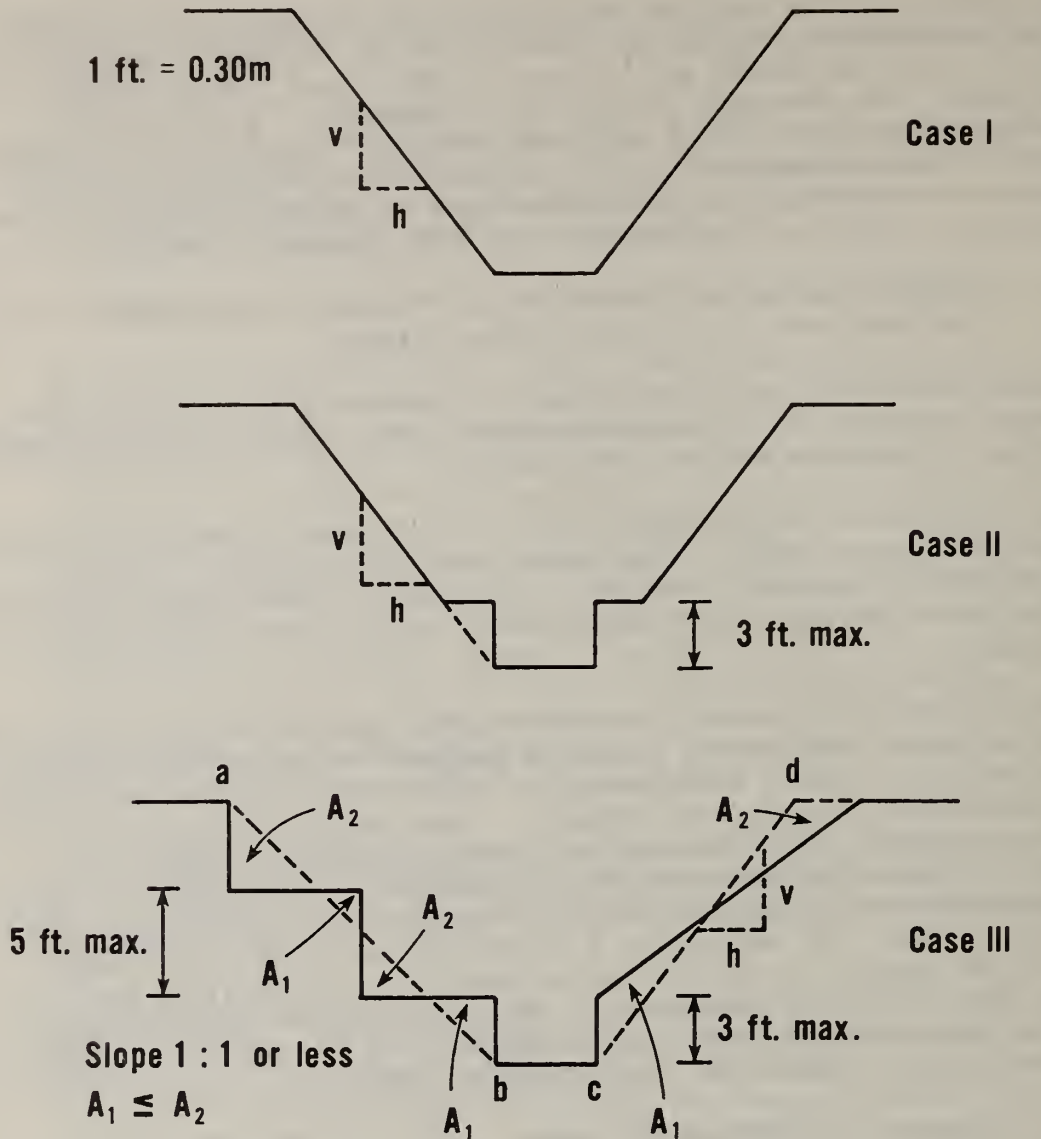
1 ft. = 0.30m

v

h

Case I

v

h

3 ft. max.

Case II

a

A_2

d

A_2

A_2

v

h

Case III

5 ft. max.

A_1

Slope 1 : 1 or less

$A_1 \leq A_2$

b   c

A_1

A_1

3 ft. max.

Case I - Ordinary slope

Case II - Compound slope with bench no more than 3 ft. high

Case III - Configuration must meet following criteria:

1. No vertical bank to exceed 5 ft., the bank adjacent to the work area not to exceed 3 ft.

2. Imaginary slopes ab and cd not to exceed max. allowable. If steps are used (left side of III) imaginary slope (ab) not to exceed 1 : 1

3. Excavated area equal to or greater than area within abcda

Figure 5.1: Recommended Allowable Configurations of Sloped Excavations
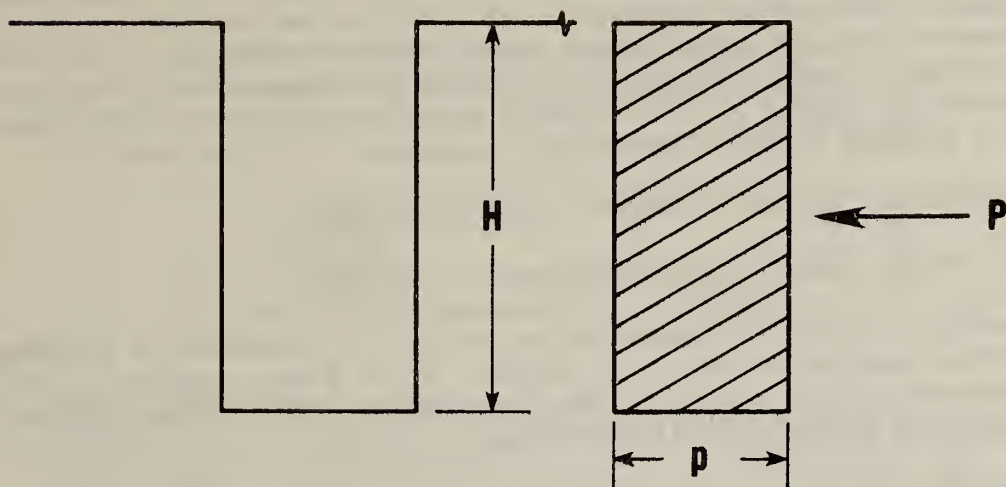
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$p = w_e (H+2)$

$P = p \times H$

H = Height of supported bank, ft.
  (2 ft. are added to allow for surcharge)

p = Distributed horizontal earth pressure, lb/ft^2

P = Resultant horizontal force per unit length lb/ft.

w_e = Lateral weight effect, lb/ft^3

Note: 1m = 0.30 ft., 1 lb = 4.5 N, 1 lb/ft^2 = 48 Pa,
      1 lb/ft^3 = 157 N/m^3

Figure 5.2: Assumed Diagram of Lateral Soil Pressure Acting
on Shoring

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for the strongest soils (A) is more restrictive. This slightly more
conservative approach was taken because even though there is evidence
that lateral pressures in shallow trenches are less than those predicted
by present engineering practice,[4] the evidence has not been corroborated
by adequate data on actual strut loads in shallow trenches. Even though
this system is more conservative than CAL OSHA Appendix C, the lateral
pressures for Type A soils are still significantly lower than those
used in present engineering practice.

The simplified system is shown in Tables 5.1 and 5.2

5.2.4 Matrix Classification System

The matrix classification system was originally proposed in Reference [22].
A modified version is presented below. It is a more sophisticated ap-
proach that permits explicit consideration of several parameters which
are implicit in the simplified system.

The matrix classification system is summarized in Tables 5.3, 5.4 and 5.5.

5.3 FIELD IDENTIFICATION

5.3.1 General

It has been noted in section 5.1.2 that a field identification method for
soil should be free of ambiguity so that any two persons classifying a
site will always arrive at the same conclusion and yet simple enough to
be useable by construction supervisory personnel. This is an ideal that
may never be fully achieved. Thus, the field identification methods pro-
posed herein are not entirely free of possible ambiguities. The authors
believe that the system can only be gradually perfected as a result of
experience gained by its application.

The following field identification methods are recommended because they
are considered suitable for rapid field decisions by construction person-
nel. Although relatively crude, they will permit identification of soil
categories and thereby provide the necessary information for bracing and
sloping decisions. The tests are not intended for engineering design.
Should an engineering analysis be desired, it is recommended that pre-
sently accepted methods of soil sampling and testing be used.

Three identification tests are proposed to permit rapid soil identifica-
tion as the work progresses. A visual-manual examination, which in most
instances will provide adequate information; strength tests to provide
improved quantitative estimates of the unconfined compressive strength
of cohesive soils in case of doubt; and drying tests to identify fissured

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[4]NBS study of widely used conventional timber shoring indicated that it
could not resist the pressures calculated by present engineering prac-
tice. [Reference 25, App. A]

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Table 5.1 Simplified Soil Classification System

Soil Type	Description	w_e lb/ft^3[a]	Steepest Slope Hor. : vert.
A	Intact Hard	20	3/4 : 1[b]
B	Medium	40	3/4 : 1[b]
C	Submerged or Soft	80	1 1/2 : 1[b]

Notes:

1. Intact Hard Soils (Type A) include stiff clays and cohesive or cemented sands and gravels[c] (hardpan, till) above the ground water table which have no fissures, weak layers, or inclined layers that dip into the trench. Stiff clays included have an unconfined compressive strength (pocket penetrometer reading) q_u = 1.5 tsf[d] or more. Intact hard soils subject to vibrations by heavy traffic, pile driving or similar effects are Type B.

2. Medium Soils (Type B) are all soils which are not Type A or C.

3. Soft Soils (Type C) include cohesive soils[c] with an unconfined compressive strength (pocket penetrometer reading) of 0.5 tsf[d] or less and soils that can not stand on a slope of 3 hor. in 1 vert. without slumping (muck).

4. Submerged Soils (Type C) are assumed whenever water drains into the trench from the soil forming the bank, or water is retained by tight sheeting, or there is a possibility that the trench may be fully or partially flooded before workers leave it or may be entered by workers, within 6 hours after more than half, of its depth was flooded and pumped out.

5. Fractured Rock shall be considered Type B when it is dry and Type C when it is submerged. Intact (unfissured) and unfractured rock is exempt from shoring and sloping requirements.

6. Layered Systems (two or more distinctly different soil or rock types, micaceous seams in rock) which dip toward the trench wall with a slope of 4 hor.: 1 vert. or steeper are considered Type C. Layered soils are classified in accordance with the weakest layer.

7. Spaced Shoring Systems (Skeleton) sheathing or skip shoring) are permitted in Type A and B cohesive soils[c] with maximum center to center spacing in accordance with Table 5.2.

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[a] 1 lb/ft^3 = 1.63 N/m^3

[b] If there is any indication of general or local instability slopes shall be cut back to a slope which is at least 1/4 hor.: 1 vert. flatter than the stable slope.

[c] Cohesive soils are clays (fine grained) or soils with a high clay content which have cohesive strength. They do not crumble, can be excavated with vertical sideslopes, are plastic (can be molded into various shapes and rolled into threads) when moist and are hard to break up when dry.

[d] 1 tsf = 96 kPa

Table 5.2   Maximum Center to Center Spacing (in feet) of Spaced Sheeting
for Simplified Soil Classification System

| Soil Type | Depth, ft[a] | |
	5-10	10-15
A	8 (6)[b]	6 (4)[b]
B	3	2

[a]   1 ft. = 0.3 m.

[b]   Numbers in parentheses are preferred spacings.

Table 5.3 Soil Classes in Matrix Classification System

Site Condition / Soil	Water in Trench No — Fissures No	Water in Trench No — Fissures Yes	Water in Trench Yes — Fissures No	Water in Trench Yes — Fissures Yes
Stiff Cohesive[a]	I	II	III	
Medium Cohesive[a]	II	III	III	IV
Granular[b]	II		III	
Soft	IV		IV	

Notes:

1. __Water in Trench__ is assumed whenever water drains into the trench from the soil forming the bank, or water is retained by tight sheeting, or there is a possibility that the trench may become fully or partially flooded before workers leave it, or may be entered by workers within 6 hours after more than half its depth was flooded and pumped out.

2. __Vibrations:__ Soils subject to vibrations by heavy traffic, pile driving or similar effects shall __always__ be assumed __fissured__.

3. __Stiff Cohesive Soils[a]__ include stiff clays and cohesive or cemented sands and gravels (till, hardpan). Stiff clays included have an unconfined compressive strength (pocket penetrometer reading) q_u = 1.5 tsf[c] or larger.

4. __Medium Cohesive Soils[a]__ have an unconfined compressive strength (pocket penetrometer reading) between 0.5 and 1.5 tsf[c].

5. __Granular Soils[b]__ are gravels, sands and silts that can stand on a slope steeper than 3 hor.: 1 vert. without spalling or slumping.

6. __Fractured Rock__ shall be treated as granular soil. Intact rock is exempt from shoring and sloping requirements.

7. __Soft Soils__ are cohesive soils [a] with an unconfined compressive strength (pocket penetrometer reading) of 0.5 tsf[c] or less and granular soils that can not stand on a slope of 3 hor.: 1 vert. without slumping (muck).

8. __Layered Systems__ (two or more distinctly different soil or rock types, micaceous seams in rock) which dip toward the trench wall with a slope of 4 hor.: 1 vert. or steeper are considered Class IV soils.

9. __Distrubed Cohesive Soils__ (backfill) shall be treated as __fissured medium cohesive__ or __soft cohesive__ soil.

10. __Spaced Shoring Systems__ (skeleton sheathing or skip shoring) are permitted in __stiff and medium cohesive soil__ with maximum center to center spacing in accordance with Table 5.5.

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[a] Cohesive Soils are clays (fine grained) or soils with a high clay content which have cohesive strength. They do not crumble, can be excavated with vertical sideslopes, are plastic (can be molded into various shapes and rolled into threads) when moist and are hard to break up when dry.

[b] Granular Soils have no cohesive strength. They normally can not be excavated with vertical sideslopes (some moist granular soils will exhibit apparent cohesion and temporarily stand on a vertical slope), they can not be molded when moist and curmble easily when dry.

[c] 1 tsf = 96 kPa

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Table 5.4 Minimum Acceptable Stability Requirements
for Matrix Soil Classfication System

Soil Type	w_e lbf/ft^3[a]	Steepest Slope hor:vert.
I	20	1/2:1
II	40	3/4:1
III	60	1:1
IV	80	1 1/2:1

Notes:

1. If there is any indication of general or local instability, slopes shall be cut back to a slope which is at least 1/4 hor.: 1 vert. flatter than the stable slope.

2. In layered soils stability requirements are set by the weakest layer.

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[a] 1 lbf/ft^3 = 1.63 N/m^3

Table 5.5 Maximum Center to Center Spacing in ft. of Spaced Sheeting for Matrix Soil Classfication System

Soil Class	Depth in ft.[a]	
	5-10	10-15
I	8 (6)[b]	6 (4)[b]
II	3	2
III	3	2

[a] 1 ft = 0.3 m

[b] Numbers in parentheses are preferred spacing.

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soils that can be readily identified visually and to differentiate between cohesive and granular material in case of doubt.

5.3.2 Visual-Manual Examination

(1) General

The recommended soil classification systems are designed for rapid field application. Normally all that is needed is a visual and manual examination of the soil and site condition as work progresses. In case of doubt or dispute the other field tests recommended herein, or more accurate laboratory or in situ tests can be used. While the methods and interpretations given herein provide guidance, they can not be substituted for common sense and judgment which may dictate attention to events and phenomena which are not discussed herein.

(2) Visual Examination

Visual examination includes examination of the site before excavation, examination of the trench and the extracted material during excavation and examination of the soil surface next to the excavated trench.

Examination of the soil surface before excavation should be for cracks (fissures), previous disturbance, surface water and vegetation (if there are known correlations between vegetation and subsurface conditions). If there are cracks (usually tension cracks from drying of clays) the soil should be considered fissured, unless the fissures are very shallow (25 percent of the excavation depth or less). Also, if previous disturbance is detected (adjacent or crossing utility lines should be considered evidence of previous disturbance) the soil should be considered fissured. Surface water may be an indication that the soil is saturated, but this is not necessarily true for impervious soils (clays), where surface water may be perched.

Examination of the soil during excavation should include several observations.

1. Can the soil stand with vertical walls? If yes, can it stand longer than 10 minutes? If not, at what slope will it stand without further slumping or spalling? If the soil can stand longer than 10 minutes it may be a hard intact (Type A) soil, or, by the matrix system, a Class I soil. A Type A (Class I soil) should stand vertically without collapse or spalling for at least 2 hours. A soil that cannot stand vertically for at least 10 minutes should not be shored by spaced sheeting. A soil that can not stand on a slope steeper than 3 hor.: 1 vert. is a "soft soil" (Type C or Class IV).

2. Is the soil dry, moist or wet? A wet soil should be considered "submerged" (water in trench) unless the ground water is lowered by dewatering of the soil forming the bank. A "moist" soil should not be considered "submerged" unless water drains from the banks into the trench.

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3. Is the soil fissured or disturbed? If not, do fissures develop a short time after excavation? If fissures either are present, or develop a short time after excavation the soil is <u>fissured</u> (Type B in simplified system).

4. Does the soil crumble or come out in clumps? If it comes out in clumps, can the clumps be broken up? If the clumps are moist or wet do they tend to slump under their own weight?

   Soils that come out in clumps are probably cohesive (a more reliable determination is discussed under manual examination). If moist or wet clumps tend to slump when dumped out of the bucket of the backhoe the soil is probably a "soft soil" (Type C or Class IV).

5. Do chunks of soil spall off the vertically excavated trench wall? If yes, this is an indication that the soil is fissured (Type B).

6. Is the soil layered? If yes, do the layers dip into the trench? This is a determination which is normally made entirely on the basis of the visual examination, by looking at the two sides of the trench.

Additionally, visual examination during excavation will reveal changed conditions such as color or moisture changes or changes in the previously discussed conditions 1. to 5.

Examination of the soil surface next to the excavated trench should be mainly for fissures parallel to the direction of the trench. If new fissures appear before shoring is installed it is usually an indication that the soil is fissured even if it was previously assumed that the soil is intact. This situation frequently arises in overconsolidated clays. In soft cohesive soils fissures next to an unshored vertical trench are an indication that the cohesive strength of the soil can not support the vertical cut. In either case shoring of appropriate strength should be selected and great caution should be exercised during its installation.

If new fissures appear next to a <u>shored</u> trench, the fissures should be taken as an indication of inadequate shoring and possibly imminent collapse. Likewise, development of new fissures next to a sloped trench are an indication that the sideslope is too steep and a slide may be imminent.

(3) <u>Manual Examination</u>

Several tests are included in the manual examination:

1. <u>Dry Strength</u>

If the soil is dry and crumbles on its own or with moderate pressure into individual grains or fine powder it is granular (sand or silt). If the soil is dry and falls into clumps which break up into smaller clumps, but the smaller clumps can only be broken up with difficulty it is a fissured clay.

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If the dry soil breaks into clumps which do not break up into smaller clumps and which can only be broken with difficulty it may be an intact clay, provided the visual examination of the trench and its vicinity did not give any indicaton of fissures.

2. Plasticity

Moist or wet cohesive soils can be molded into various shapes and rolled into threads as thin as 1/8 in. (3 mm) without crumbling. If at least a 2 in (50 mm) length of an 1/8 in thread can be held on one end without tearing the soil is cohesive (though it may be fissured).

3. Thumb Penetration

The thumb penetration test (see Table 3.3) can determine the strength of cohesive soils. Type A (Class I) soils can be indented by the thumb, but can only be penetrated with very great difficulty. Type C (Class IV) soils can be easily penetrated several inches by the thumb.

(4) Visual-Manual Examination by ASTM D2488-69 [1]

Some of the methods described in this section are compatible with ASTM D2488, however the approach is simplified and lends itself to a more rapid application. In case of doubt or dispute ASTM 2488 could be used with the following interpretation:

Cohesive soils are clayey silt, sandy clay; silty clay, clay, and organic clay that have dilatancies ranging from rapid-slow to none and "toughness of plastic thread" ranging from medium stiff to very stiff.

Consistency: Soft cohesive soils are defined as in ASTM, Table 1. Hard Intact Soils (stiff cohesive in matrix classification) cover the upper range of "very stiff" and "hard" as defined in ASTM Table 1 (1.5 ton/ft^2 and up).

(5) Visual Identification of Distress

"Distress" is defined herein as a situation where a shored or sloped trench is at the verge of total or partial collapse. Not only construction superintendents, but all workers entering or working next to a trench should be trained and instructed to identify and watch for signs of distress. There are two phenomena which are often associated with distress:

1. Development of new fissures parallel to a shored or sloped trench.

2. Sudden separation of even minor amounts of soil from the slope, or the vertical bank in spaced sheeting (pebbles or little clumps rolling off the bank or sands beginning to trickle down). The term "ravelling" is often used to describe this phenomenon.

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5.3.3 Strength Tests

A crude approximation of the unconfined compressive strength of cohesive
soils can be obtained by use of a pocket penetrometer. The pocket pene-
trometer should be utilized in place, preferably in the sides of a
freshly-opened trench (workers performing the test must be protected by
shoring). Tests should be made at locations no further apart than 10 ft
(3m) horizontally along the trench or wherever the soil type changes.
At each location, several tests should be made on each side of the
trench preferably at 1/3 and 2/3 the depth and near the bottom if mois-
ture content increases with depth. If it is dangerous to enter the
trench, tests could be performed on soil clumps removed from the trench.

As an alternative to the pocket penetrometer, a hand operated shearvane
may be used. In this case, readings should be doubled to obtain unconfined
compressive strength. There may be a tendency to consider the results
of shearvane tests as more reliable than is justified.

5.3.4 Drying Tests

The basic purpose of the drying test is to differentiate between granu-
lar materials, cohesive materials with fissures, and intact cohesive
materials. The test must be conducted on undisturbed samples, perhaps
taken with an ordinary shovel, since they will identify fractures, fis-
sures and slickensides in cohesive soils as well as the coarse-grained
component of other materials.

The procedure for the drying test involves drying a sample of soil
approximately 1/2 to 1 inch (12 to 25 mm) thick and 6-inches (150 mm) in
diameter. The sample can be dried in an oven at 212°F (100°C) for 24
hours. Other field methods could be used, such as placing the sample on
a hot engine exhaust manifold or baking the sample in the sun during
hot weather. If significant fissures exist, they will become apparent
upon drying as the sample will crack along the fissures. If the sample
dries to a hardened state intact it should be broken by hand as described
in the following paragraph.

After drying, the sample is grasped between the thumb and forefinger of
each hand and broken in flexure. If considerable force is necessary to
break the sample, the soil has a significant clay content and should be
classified as a soft, medium, or stiff clay without significant fissures
or joints (intact). If the sample can be easily broken, the soil is
either a fissured clay or a granular material. Distinction between a
fissured clay or a granular material can be made by attempting to pulver-
ize the resulting dried clumps of material. A simple means would be to
squeeze them together in one hand. (Even stepping on them is all right.)
If they pulverize into very small fragments, the material is granular.
If the clumps do not pulverize easily, the material is a fissured clay.

5.3.5 Suitability for Spaced Sheeting

When the material is granular, spaced sheeting is not feasible since the material would collapse. This is in most instances evident and no tests are needed. A dangerous situation may however arise when the material stands up long enough to make installation of supports feasible but subsequently collapses between supports. This situation may arise in fissured clays as well as in moist soils which are predominantly granular. In the latter case, failure may occur with a change in moisture content. The following conditions are necessary, but not always sufficient for the feasibility and safety of spaced sheeting.

1. The trench, when fully excavated, should stand up with vertical walls for at least 10 minutes if spaced sheeting is to be used at all. It should be able to stand 2 hours without any sign of failure if the center to center spacing allowed for Type A (Class I) soils is to be used.

2. For spaced sheeting to be permitted at all it should be possible to pick up the dried drying test specimen on one end without breakage.

5.4 CLASSIFICATION PROCEDURES

5.4.1 Simplified Classification System

The classification procedure is outlined in the following flowchart. Note that in most instances all the steps can be accomplished in the visual-manual examination.

Additional decisions are needed when spaced sheeting is used according to Table 5.2. Two decisions are necessary:

1. Can spaced sheeting be used? If the soil crumbles and a portion of the trench will not stand for 10 minutes without support, spaced sheeting cannot be used. If the trench does stand up but there is a question whether adequate cohesive strength is available, an additional determination can be made by the drying test.

2. Is the soil Type A or B? This decision was previously described and can be in most instances easily resolved by thumb penetration or penetrometer tests. Trenches in Type A soil should also be capable of standing without support for two hours.

FLOW CHART FOR SOIL CLASSIFICATION PROCEDURE, SIMPLIFIED CLASSIFICATION SYSTEM

TABLE 5.1, NOTE 4 — SUBMERGED? — YES

NO

TABLE 5.1, NOTE 6 — INCLINED LAYERS DIPPING TO TRENCH? — YES → TYPE C

NO

TABLE 5.1, NOTE 3
IF COHESIVE:
THUMB IMPRINT TEST
or PENETROMETER TEST
or TORVANE TEST — SOFT? — YES

NO

TABLE 5.1, NOTE 1
VISUAL EXAMINATION
or THUMB IMPRINT TEST
or PENETROMETER TEST — HARD? $q_u \geq 1.5$ tsf — NO → TYPE B

YES

VISUAL EXAMINATION
or MANUAL EXAMINATION
or DRYING TEST — FISSURED? — YES

NO

TYPE A

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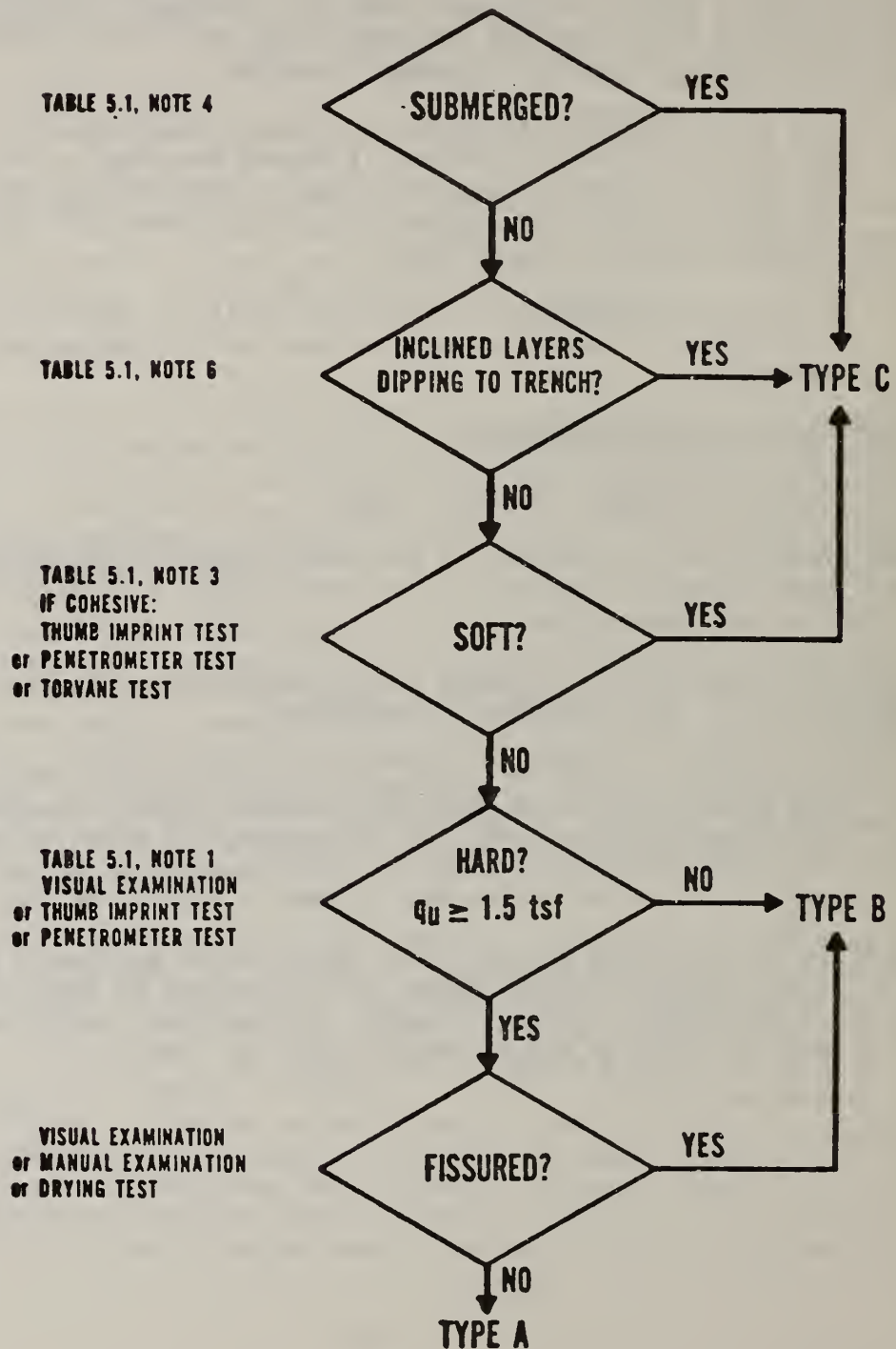
5.4.2 Matrix Classification System

In this system, more parameters are considered and thus, more decisions must be made. The procedure is outlined in the following flow chart.

FLOW CHART FOR SOIL CLASSIFICATION PROCEDURE,
MATRIX CLASSIFICATION SYSTEM

(1) Table 5.3, Note 8
(2) Table 5.3, Note 3
    Visual Examination
    Thumb Penetration
    Penetrometer or vane
(3) Table 5.3, Note 5
    Visual Inspection
    Drying Test
(4) Table 5.3, Note 1
(5) Table 5.5, Note 4
    Thumb Penetration
    Pocket Penetrometer or vane
(6) Visual Examination
    Manual Examination
    Drying Test
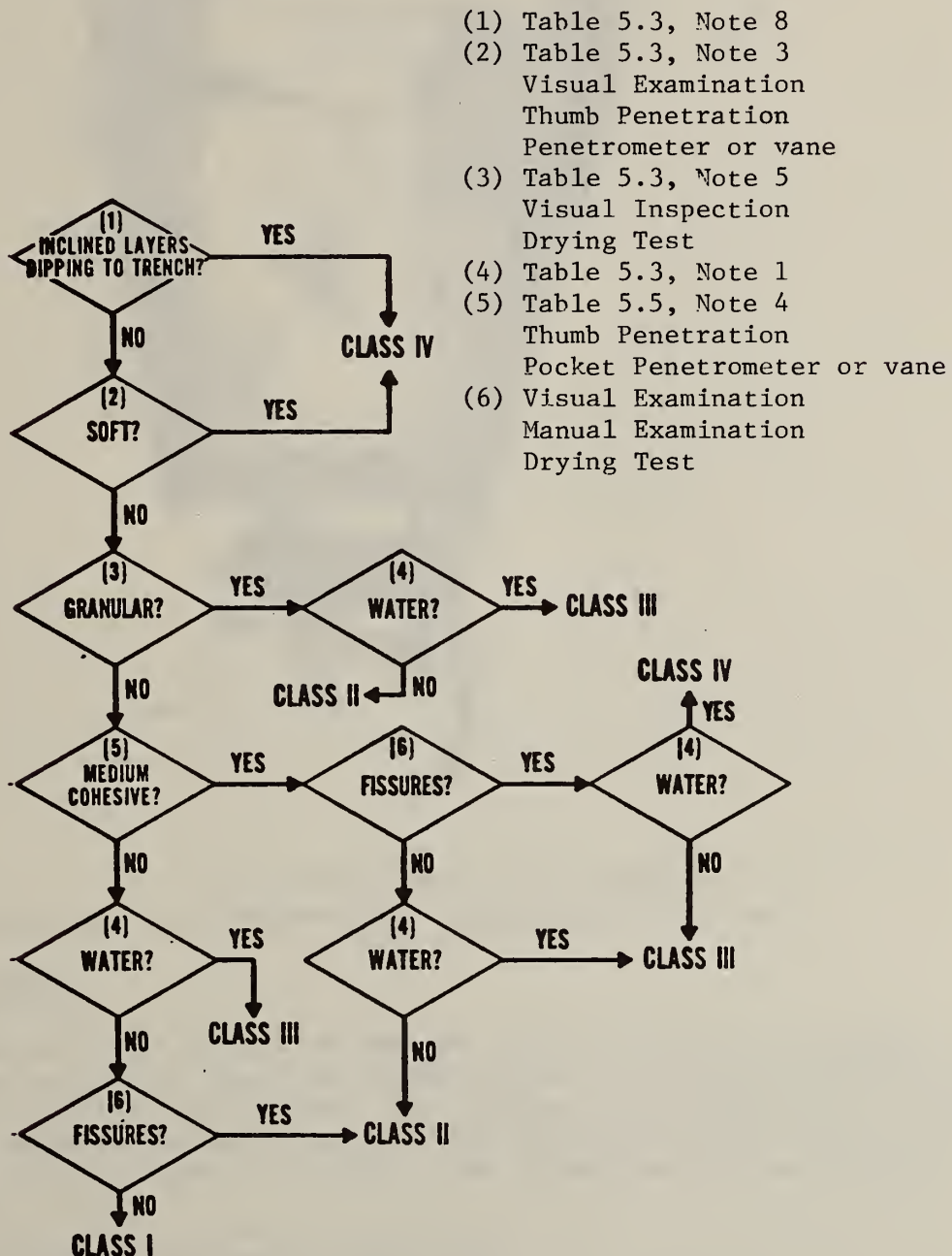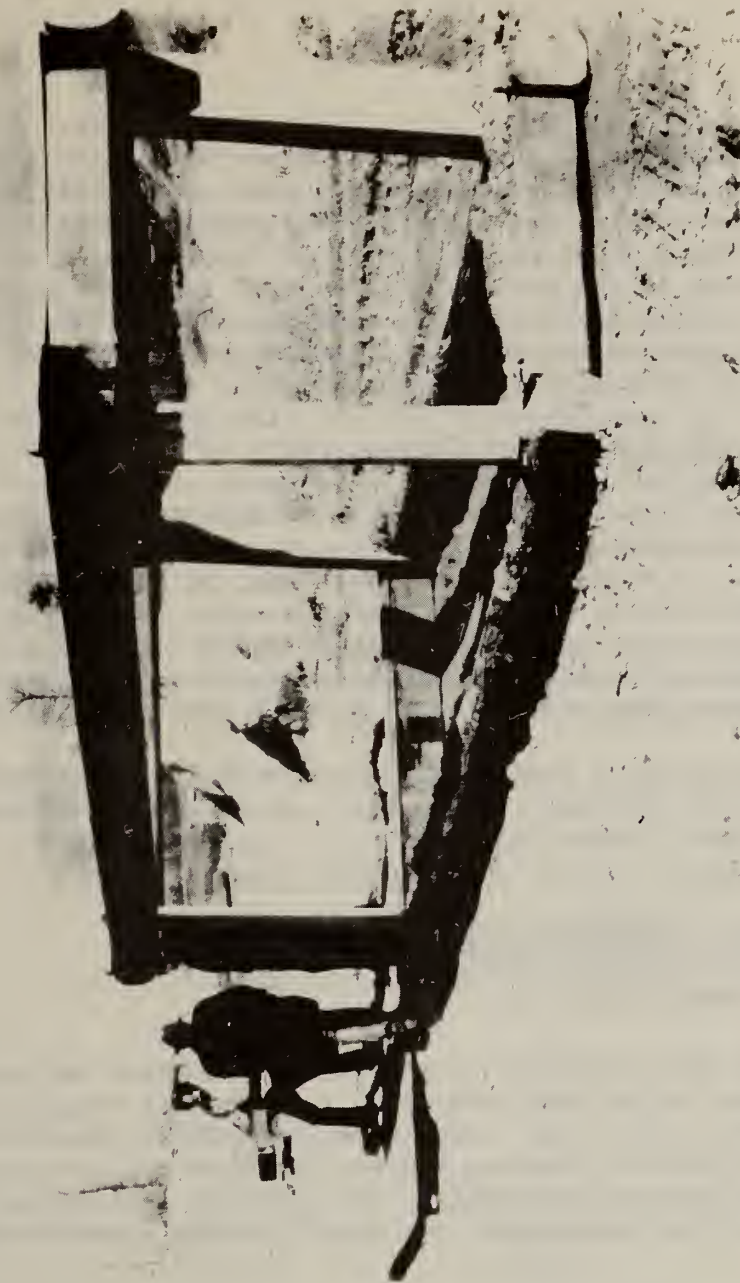
Prefabricated strut-wale assembly

6. COMMENTARY ON RECOMMENDED SOIL CLASSIFICATION SYSTEMS

6.1 GENERAL

Two alternate systems are recommended, each of which has advantages and disadvantages which should be carefully scrutinized by the intended users before a final choice is made. The success of any system will ultimately depend on its acceptance by all the parties involved and on the ability of the intended users to apply it. One of the two systems should be adopted.

6.2 ALLOWABLE SIDESLOPES (Figure 5.1)

The sloped excavation configurations shown in Figure 5.1 are suggested in order to give more flexibility to contractors. Vertical sides are frequently required in specifications for pipe bedding. The configuration

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in Case II would permit contractors to meet these specifications. In Case III any configuration is permitted that would provide overall stability (not necessarily local stability) equivalent to that of the sloped excavation. The 3-ft (1 m) limitation of the height of the vertical unsupported bank in the vicinity of the work area is provided to minimize the effects of a potential localized collapse. The 5 ft (1.5 m) limitation on the height of any vertical unsupported bank in Case III is consistent with present OSHA regulations.

6.3 LATERAL PRESSURE DIAGRAMS (Figure 5.2)

The simple soil classification systems recommended do not provide the information necessary for the selection of one of the design pressure diagrams shown in Figure 3.1. For instance, it is not always necessary to distinguish between sands and clays in order to use the Simplified System. Moreover, surface deposits are frequently heterogeneous and can not be readily placed into one of the categories in Figure 3.1. The uniform pressure diagram was chosen for all soil conditions.

A 2-ft (0.6 m) uniform surcharge is used to allow for accumulation of spoil, stored construction material, machinery, traffic or any other surcharge effects (normally construction equipment operates from one side and the spoil pile is on the other side).

6.4 SIMPLIFIED CLASSIFICATION SYSTEM (Table 5.1)

6.4.1 Soil Types (Table 5.1)

The intent of this system is to provide the simplest and least ambiguous scheme possible while still providing a reasonable range of choices to the contractor. It is felt that in most practical situations, three strength categories of bracing systems is all a contractor would want to use. However, should intermediate strengths be desired, an engineer could document the adequacy of the shoring using accepted engineering practice.

The decisions that must be made in order to classify a site are shown in the flow chart in Section 5.4.1.

6.4.2 Lateral Soil Pressures (Table 5.1)

In Table 6.1 the lateral soil pressures (weight effects) recommended for the Simplified System are compared with those calculated by accepted engineering practice in accordance with Figure 3.1. It can be seen that the Simplified Method is equal to, or more conservative than, accepted engineering practice for sands and soft clays, roughly equal for stiff clays, dense cohesive sands or stiff sandy clays and on the low side for medium clays. [Note that the upper limit for medium clays was calculated for the borderline case of 500 psf (24 kPa) cohesion and 20 ft (6 m) depth. This is an extreme case which in reality would be Type C (the stability number for medium clays, and thus the pressure

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coefficient increases with depth)]. The reason for setting these values
lower is based on several observations: (1) The CAL OSHA experience
which extends over two decades produced no evidence of unsafe conditions;
(2) Analysis of traditional timber shoring leads to the conclusion that
actual field conditions for shallow trenches produce pressures which
are much lower than those predicted by engineering analysis; (3) The
nature of shallow trenches, which are open for short time periods and
are generally excavated to their full depth before shoring is installed
(particularly in clays) and where the stability number (N) tends to
be low. These conditions will produce lateral forces in shallow trenches
which are much smaller than those measured in deep excavations (see
discussion Section 4.1). Nevertheless, before the system is actually
adopted, consideration could be given to changing the definition of
the "soft soil" category for clays and including clays with an unconfined
compression strength up to 1500 psf (72 kPa).

Table 6.1 does not include submerged sands and organic soil; however, in
both of these instances the Simplified System tends to predict lateral
pressures which exceed those calculated by engineering analysis.

Table 6.1 Comparison of Lateral Weight Effects Calculated by Various
           Methods

Soil Type	w_e, lbf/ft^3		
	Eng. Practice	Simplified System	Matrix System
Loose Sand	25-26	40	40
Med. Sand	20-25	40	40
Dense Sand	17-20	40	40
Soft Clay	40-80[b]	80	80
Med. Clay	44-70[b]	40	40-60[a]
Stiff Clay (N<4)	22-33	20-40[a]	20-40[a]
Dense Cohesive Sand	20-30	20-40[a]	20-40[a]
Stiff Sandy Clay	20-30	20-40[a]	20-40[a]

[a] Value that would be used if clay is fissured.

[b] Value changes with depth of trench.

6.4.3 Allowable Slopes (Table 5.1)

The philosophy used for allowable slopes substantially differs from that
used in the present OSHA regulations, Table P-1 [9]. Instead of stipu-
lating "stable" slopes for many different conditions, the "steepest
allowable" slope of 3/4 horizontal to 1 vertical is stipulated for
"intact hard" and "medium" soils. It is reduced to 1-1/2 horizontal to
1 vertical for "submerged and soft" soils. It is realized that the
stipulated maximum allowable slope will not be stable in many instances.

For example, dry sands will not stand on an angle steeper than their angle of shearing resistance. However, in those instances the contractor will be unable to excavate at a steeper angle, and thus, the resulting excavation will be safe. On the other hand, the NBS field study indicates that in many instances construction slopes in short-term excavations are steeper than the maximum stable slopes that would be predicted by engineering calculations. This is particularly true for moist sands and silts where apparent cohesion stabilizes slopes steeper than the angle of shearing resistance. This and similar conditions are very difficult to quantify and rigid limitations, which by necessity are based on the worst case, would be unrealistically conservative and thus difficult to enforce. The difficulty of enforcing multiple choices of sideslopes was confirmed in the NBS field study [7] where many comments expressed unhappiness with existing provisions for sloping.

In recognition of these difficulties the approach recommended herein is similar to the one used when speed limits are enforced for vehicles on highways. The maximum allowable speed is not reasonable under all conditions (i.e., ice, rain, etc.) but it is the only speed that can be realistically enforced, since the "reasonable" speed is too difficult to quantify.

As an added protection, footnote "b" in Table 5.1 stipulates that if there is any sign of general or local instability the slope shall be cut to an angle which is flatter than the stable slope as observed in the field.

There are several reasons for the stipulated steepest allowable slopes. In stiff and medium clays these slopes will be stable for depths up to 20 ft. It can also be shown [16] that as the shear strength of a clay decreases and the excavation depth becomes critical, a base failure will occur even if the slope is flattened; for sands and silts as indicated before, this slope should be viewed as a maximum that in many instances cannot be attained. Data from the NBS field study, as well as experience with a similar provision in California indicate that the proposed maximum slope provision should work well in practice, as long as it is understood by contractors that this is a maximum allowable slope which is not necessarily appropriate for all cases. The flatter 1-1/2 horizontal: 1 vertical slope was proposed for "submerged and soft soil" to allow for potential instability caused by water seeping into the trench. In many of the "submerged" and "soft soil" conditions, sloping is not appropriate and would not be used by contractors.

6.4.4 Spacing of Spaced Supports (Table 5.2)

The maximum spacings correspond to existing practice and present OSHA provisions. Spaced supports are not always feasible for Type B soils. A procedure for field determination of whether spaced sheeting can be used is outlined in Section 5.4.1.

6.5 MATRIX CLASSIFICATION SYSTEM

6.5.1 Soil Classes (Table 5.3)

In this classification system the two important parameters of water and fissures are interfaced with four different soil types. This allows consideration of 16 possible situations. The advantage gained by this approach is that the important parameters are explicitly considered. This is accomplished at the expense of added complexity since it requires more decisions which require knowledge of soil properties and better training of the personnel that must make these decisions.

6.5.2 Lateral Soil Pressures (Table 5.7)

Comparison of the lateral soil pressures obtained by the Matrix System with those obtained by the Simplified System (see Table 6.1) indicates that for the cases tabulated (except for medium clay) the pressures are identical. However, there are differences for other cases. These are shown in Table 6.2 together with average pressures calculated by accepted engineering practice (actual pressures would change with depth). It can be seen that for submerged stiff clays and sands the pressures used in the Matrix System are closer to those used in engineering practice. In any particular case, the pressures computed by engineering practice may be even lower, since the "submerged" case includes every instance where water enters the trench, which includes cases where only part of the depth of the retained soil is submerged. If the Simplified System was to be used, the contractor would have the choice between using the conservative 80 lbf/ft^3 (130 N/m^3) pressure or retaining an engineer. In view of the fact that shallow excavation work is only rarely conducted below the groundwater table (in preference of dewatering) the involvement of an engineer in this situation seems reasonable and even desirable.

Table 6.2   Cases Where Lateral Soil Pressures Obtained by the Matrix System Differ from those Obtained by the Simplified System

Soil Type	w_e, lbf/ft^3		
	Eng. Practice	Simplified System	Matrix System
Submerged Med. Sand	43[a]	80	60
Submerged Stiff Clay	44–45[a]	80	60
Submerged Med. Clay	55–70[a]	80	60
Submerged Fractured Rock	52–80[b]	80	60

[a]Since by hydrodstatic pressure increases linearly with depth, 1/2 the effect of hydrostatic pressure was added to make a comparison possible.

[b]Pressures were taken from Reference [10].

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6.5.3 Allowable Slope (Table 5.7)

While the slopes in the Matrix System, like those in the Simplified System, are maximum slopes they permit a distinction between soil types and also provide more guidance to the contractor. Note that a 1/2 horizontal to 1 vertical slope is permitted for Class I soils (Category A). This slope is not permitted in the Simplified System, where the emphasis is on elimination of complexity. Experience indicates that slopes are difficult to determine in the field and generally look steeper than they are. Thus, a 1/2:1 slope will have the appearance of a vertical cut. With even slight irregularities, a 1/2 horizontal in 1 vertical slope may actually become a vertial cut over large portions of an excavation. Thus work would have to be performed very carefully if 1/2 horizontal in 1 vertical cuts were to be used.

6.5.4 Spacing of Spaced Supports (Table 5.5)

The commentary in Section 6.4.4 also applies to Table 5.5.

6.6 FIELD IDENTIFICATION

6.6.1 Resolution of Conflicts

For both proposed systems visual-manual examination is all that is normally needed. However, decisions must be made on the basis of this field examination, and the question arises how conflicting opinions about the validity of these decisions are resolved. For the Simplified System there are two decisions where conflicting interpretations could arise: (1) is the soil "intact hard"?; (2) is the soil soft?

For intact hard soil there are three criteria:

a. There shall be no fissures.
b. The shear strength exceeds 1500 psf (72 Pa).
c. The excavated trench can stand without support (there is no sign of any distress after two hours).

For (a) there are three methods: visual examination, manual examination, and the drying test. All of these procedures will not always give repeatable results, because soil is a heterogeneous material, tension cracks come and go with the seasons and the drying test is not a very exact tool. Thus, there are some inherent difficulties in this instance.

The ultimate test would be that the trench should be able to stand unsupported for at least two hours without spalling or collapse.

For (b) there is a "hierarchy" of tests in terms of level of accuracy. At the bottom is the "thumb penetration test" (Table 4.3). At the next higher level are the "penetrometer" or "vane" tests for cohesive soils. At a still higher level are in situ tests: the Standard Penetration Test

[6], Cone Penetration Tests (ASTM D3441-75T) and Vane Shear Tests (ASTM D2573-72). At the top of the hierarchy, provided that an undisturbed sample can be taken, would be laboratory tests such as the Unconfined Compression Test [ASTM D2166-66 (1972)].

For (c) the test is not ambiguous in itself, but it is quite possible that two sections of trench, excavated in the same general area and condition, would behave differently. To determine whether a soil is "soft" the same heirarchy of steps as described under (b) above applies if the soil is cohesive. For cohesionless soils compliance with the provision of a 3 horizontal: 1 vertical stable slope can be determined visually. At a higher level an engineer could determine the angle of shearing resistance by in situ or laboratory tests.

For the Matrix Classification System, one more potentially ambiguous decision is whether a soil is "granular". Again, visual-manual examination will in most instances provide an answer. After this, the procedure described under the drying test (Section 5.5.4) could be followed; the next more accurate step would be conventional soil classification (D-2487-69) [4]. The ultimate judgment could be made by determining the cohesive strength (c) and the angle of shearing resistance (ϕ) in a triaxial test. ϕ should be more than 18°, otherwise the soil would be a "soft soil".

6.6.2 Drying Test (Section 5.3.4)

This is a new test, even though it has some similarity with procedures described in ASTM D2488-69 [5]. However, the ASTM procedure involves remolding which would obliterate the in-situ fissures.

The Drying Test is to be conducted on an undisturbed sample. The test should be relatively insensitive to technique and to sample size, as long as the sample is large enough to include likely fissures and as long as the sample is adequately dried. After some experience is gained in the field, the drying test should be quantified with standardized sample sizes and testing procedures.

It should probably be mentioned that temporary shoring should be placed in a trench while taking any test samples.

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8. ACKNOWLEDGMENTS

The contribution of the following persons is gratefully acknowledged.

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Trenching machine used in trench braced by hydraulic shores

APPENDIX

BACKGROUND INFORMATION ON
TRENCHING PRACTICE AND ACCIDENTS

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A.1 GENERAL

The background information presented herein was compiled in
Reference [22].

A.2 BACKGROUND INFORMATION

A.2.1 SOURCES OF INFORMATION

Very little published information is available which provides quantita-
tive data regarding trenching failures or lateral earth pressures
against shoring in braced shallow trenches and moreover trenching prac-
tices vary widely in different geographic regions of the nation.

Thompson and Tannenbaum [18, 19, 20] presented results of extensive sur-
veys of accident reports and contractor opinions. The National Bureau
of Standards [7, 22] obtained data regarding trenching practices among
members of the National Utility Contractors Association and interviewed
selected utility contractors to determine their practices with regard
to soil identification and trench bracing. The Associated General Con-
tractors conducted a questionnaire survey in 1977 [12] which yielded
further information. In addition, reports of fatal accidents of 1973-
74, given by OSHA Compliance Officers, have been reviewed in an attempt
to determine common causes or characteristics of trench cave-ins.
Results of some of these sources are discussed below.

A.2.2 THE THOMPSON AND TANNENBAUM DATA

A report was written in 1975 [18] from data accumulated in a study
funded by the Associated General Contractors of America. Basic sources
of information came from 86 major newspapers and 120 questionnaires
returned by contractors. The newspaper clippings identified both a
variety of soil types, mentioned in section 1, and many others as pos-
sible contributors to trenching collapses. Of 120 contractors
responding, 52 reported a total of 85 cave-ins during the history of
their companies. Information of soil types in the contractor reports
were sketchy, but cave-ins in all types of conventionally identified
soils were reported. Probable factors other than soil conditions which
were mentioned as contributing to cave-ins were excessive rainfall, see-
page, vibrations, and equipment near trenches. The majority of the
failures reported by Thompson and Tannebaum were in trenches less than
20 ft (6 m) deep [18].

A.2.3 NBS FIELD STUDY

As a portion of the overall NBS study, Hinze [7] interviewed contractors
and their staff and analyzed results from a survey conducted by the
National Utility Contractors Association (NUCA). The NUCA survey had
223 responses. Ninety-three percent of the trenching work of responding
contractors involved depths of 15 ft (4.5 m) or less. About 75 percent
reported average depths to the water table less than 15 feet. Trench

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widths were seldom more than 6 ft (2 m). All types of soils were
encountered, and most contractors mentioned both wet and dry conditions.
Over 75 percent of the contractors reported less than 100 ft (30 m)
of trench open at any one time. Contractors seldom employ soils engi-
neers. A considerable amount of additional data related to safety prac-
tices and firm characteristics was assembled in an NBS field study [7].

A.2.4 INTERVIEWS WITH SELECTED CONTRACTORS

Tucker and Reese [22] held interviews with 15 selected contractors,
city officials, manufacturers of shoring equipment, and safety offi-
cials. In general, the interview results were consistent with the
data obtained from Reference [7].

Most contractors work within a radius of 50 miles of their offices and
in soils with which they are generally familiar. They seldom have soil
boring results available prior to bidding or starting a project. Even
if such data are available, they are considered unreliable by the con-
tractors. If contractors have concern about a site, they take a back-
hoe out and dig a test section to determine site characteristics. In
such cases, contractors are normally looking for depths to rock and
water, rather than soil characteristics.

All contractors interviewed prefer to slope trench sides for stability,
as compared to any other safety system. Some will slope even if the
trench walls could stand vertically, because of backfill convenience.
There are instances, however, where right-of-way restrictions require
vertical sides. All contractors use hydraulic backhoes extensively.

Decisions regarding trench bracing are normally made by job-site super-
visors. Some contractors state they would always have a supply of
shoring material onsite to minimize the inconvenience factor in a
shoring decision. Although shoring slows work slightly, it is not
normally considered a major factor for decision. The unanimous atti-
tude of those interviewed was that safety takes the highest priority
and that job foreman or superintendents are encouraged to take safety
precautions if they have any doubts regarding stability.

Job site supervisors have major responsibilities for decisions. Super-
intendents and foremem normally have several years experience. Even
contractors with registered engineers on their staffs consider the job
supervisors as more capable of identifying soils and determining shoring
needs. Most soils are defined by local generic terms rather than geo-
logical or geotechnical terms.

A variety of crude tests and indicators are used for soil types and
stability indicators. The necessary slope angle is normally determined
by the backhoe operator who may strike a trial slope several times with
the backhoe bucket. If he can induce sloughing in this matter, he will
flatten the slope. Many contractors said they looked for backhoe teeth
marks in the excavation. If these are presented and make clear indenta-

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tions, it is an indication of significant clay content. Other contractors watch surface crack movements, kicking loose soil into them and watching for progressive opening. Many mentioned signs of "ravelling" in clay soils and surface spalling on the trench sides indicating movement or embankment distress.

Most contractors expressed fears of "stable" soils that collapsed suddenly. They also felt that most accidents are caused by carelessness of field personnel, who fail to exercise proper precautions in known unstable environments. Many mentioned such things as "layered" soils, "fissured" clays, trenches left open too long, rainfall or seepage water, trench discontinuities, vibrations, and disturbed soils as hazardous situations.

A.2.5 THE ASSOCIATED GENERAL CONTRACTORS (AGC) QUESTIONNAIRE [12]

The Safety Division and Municipal Utilities Division of the Associated General Contractors distributed a lengthy survey questionnaire in late 1977, which received 23 responses from a wide geographic area. Of the work performed by the 23 respondents, about 70 percent was for seepage, and 23 percent for water systems. Fifty percent of the work utilized sloped sides, while bracing systems were used an average of 43 percent of the time.

Typical soil conditions encountered by the respondents were:

Stiff clay	29 percent
Medium clay	18 percent
Soft clay	16 percent
Sand and gravel	15 percent
Loose sand	10 percent
Muck	6 percent
Loess	6 percent

Written responses were given regarding the soil type causing the most concern for safety against collapse. Although these varied somewhat, the most frequent responses were "clay likely to crack" and loose silt or sand."

Most contractors (79 percent) stated that they normally left their trenches open less than one day. Almost half of the trenches are left open less than 2 hours. The typical length of an unbraced trench section averaged 40 feet (12 m) and the typical length of a braced section averaged about 50 feet (15 m).

As indicated by the interviews with contractors, the questionnaire showed a preponderance of decisionmaking authority with job site supervisors. General superintendents and foremen are heavily involved with all decisions regarding bracing and sloping. The job foreman or superintendent is almost universally considered to be the person most familiar and qualified to describe the physical characteristics of a soil.

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One question related to the uniformity of soils from the ground surface to the bottom of the trench. Of those responding, 75 percent stated that soils in their region are normally not uniform. Responses indicated many combinations, but both soils increasing in strength and soils decreasing in strength with depth were mentioned. Soils changing radically in character, such as granular to cohesive were frequently mentioned.

Responses to the question regarding site conditions causing the greatest safety hazards were as follows:

Straight trench	6 percent
Manholes	4 percent
Intersections of trenches	23 percent
Vibrating areas	14 percent
Disturbed soils	38 percent
Narrow right-of-way	14 percent

Another question was posed regarding "surprises" during a trenching project. Answers were given in terms of frequency of occurrence. Responses were as follows:

	Frequently	Occasionally	Rarely
Unexpected Ground Water	3	10	9
Radical Change in Soil Type	9	8	5
Tree Roots	3	11	8
Unanticipated Utility Lines	8	11	3
Previous Excavations or Disturbed Soil	3	15	4
Unusually Heavy Surcharge	0	7	10

The contractors were asked if they frequently encountered soils which lose stability due to a variety of causes. Responses are tabulated below.

Rainfall	12
Vibration	13
Increased Subsurface Water	13
Drying	11
Temperature Changes	2
Inclined Bedding	3

Survey responses suggest that moisture changes and vibration have significant effects on soil stability.

In summary, a wide variety of soils is encountered by trenching contractors. Soils often vary with depth in a trench. Unexpected conditions often occur and soils may lose stability with time due to weather or environmental factors.

A.2.6 OSHA COMPLIANCE OFFICER REPORTS FOR 1973-1974

As a means of gathering information on actual failure circumstances and situations, 64 reports from OSHA Compliance Officer investigations during 1973-74 were furnished by OSHA in September 1977. These have been reviewed and the results summarized [22]. Although the data are sketchy, the pertinent results are discussed below.

Collapses normally occurred in rather shallow trenches. Of the 46 cases in which trench depths were given, 40 were less than 12 ft (3.7 m) deep. Soil identification was not normally made in an extensive fashion. However, of the 29 instances in which soil was identified, 17 cases occurred in soil classified as "disturbed or fill." Free water was noted in seven instances, although no mention of water was made in 56 cases.

In at least 2 cases, vibrations were assumed to be contributing to the accidents. Another 23 locations were near streets or railroads which are possible sources of vibrations. Fourteen of the locations were not near possible vibration sources. No information was given in 23 other instances.

Of the 54 instances in which information was available, 42 of the failures occurred in straight sections. Discontinuities of the trenches were possibly involved in 12 failures.

Secondary collapses of the opposite walls of the trenches were noted in 5 instances.

No information was given regarding sloping or shoring in 20 of the 64 cases. In those where information was available, 4 failures were in sloped trenches, 6 failures had skip shoring, 7 tight sheeting and 2 trench boxes. Twenty-two occurred in trenches with no shoring. Six accidents occurred during installation or removal of shoring.

In accordance with this data sample failures generally occurred during good weather. The injured workmen were normally mature individuals. Of the oldest persons injured, 40 were over age 30 and 18 were over age 50. This information is consistent with that from the contractor interviews [21]. Job site personnel are often experienced and tend to stay with a contractor for many years. Thus, the number of accidents involving older, and presumably more experienced, personnel tends to refute arguments that experience is an adequate factor in judging trench wall stability.

It is unfortunate that more data are not contained in the Accident Reports. These could be the most valuable source of quantitative

information available regarding failure conditions. Such items as
trench dimensions, soil properties and identification, and details
of shoring systems would be invaluable.

A.2.7 SUMMARY OF BACKGROUND INFORMATION

Most of the background data were obtained from contractor questionnaires
or interviews, or from case histories of accidents. Very little data
of a quantitative nature are available, that could be used to quantify
numerical approaches to problems of trench stability. Soil properties
often vary widely both from the top to the bottom of a trench and
linearly along a trench. Job site personnel are considered by contrac-
tors the most qualified persons to judge trench stability and to deter-
mine necessary support measures. Such supervisory personnel normally
have several years experience in the area of work. However, the number
of fatalities and accidents involving experienced personnel indicates
that decisions on sloping and shoring should not be based solely on
experience.

It is apparent that many factors other than those identified in a con-
ventional soil characterization influence trench stability. The more
important factors include soil cracks and fissures, free water, previous
disturbance, vibrations, and weather. Time is obviously a critical item,
as trenches will remain open long enough for some activities, but col-
lapse suddenly after a period of time.

A.3. TRENCHING CHARACTERISTICS AND PRACTICES

A.3.1 GENERAL

In current practice in the United States, most utilitiy contractors pre-
fer to stabilize the sides of trenches by sloping rather than by bracing.
This attitude is, in part, the result of the fairly recent development
and introduction of the hydraulic backhoe in the industry. These
machines enable contractors to dig and handle a wide range of soils at
rapid rates. A significant number of the utility contractors engaged
in new subdivision work have organized their entire operations around
the hydraulic backhoe and do not go into a detailed design of most of
the trenches they dig. Instead, they depend on past experience on jobs
in the local area in submitting a bid. They rely on their job foremen
and/or backhoe operators to slope the trench sides adequately to ensure
stability during the relatively short period the trench will be left
open. In deep trenches or in highly non-cohesive soils, they often
resort to a combination of methods; sloping the sides of the upper
portion of the trench and bracing the lower portion. Many of the con-
tractors will not bid on a project when conditions dictate extensive
bracing of the entire trench.

For water lines and other relatively small trenches, trenching machines
are sometimes employed to cut vertical sides which are seldom braced
because workmen can easily get out of the trench if the sides fail.

There are, however, some jobs involving deeper trenches and vertical sides, particularly in urban areas. A small number of contractors employ large trenching machines on these projects and rely upon bracing to ensure stability of the sides. A similarly small number of contractors concentrate on jobs involving rock, and employ drilling and blasting to fracture the material so that it can be excavated. These contractors cut vertical trench sides and do not use bracing except when inclined bedding makes it necessary. If a given project requires several types of trench work, the successful bidder frequently subcontracts the portions his crews are not familiar with.

A.3.2 RIGHT-OF-WAY

Restrictions imposed by narrow right-of-ways often make some form of bracing necessary. This is particularly true in urban areas, where interference with traffic or other utilities cannot be tolerated. In older cities, these conditions are often further complicated by disturbed soil from earlier projects, which makes stabilization by sloping less dependable. Bracing, rather than sloping, is also necessary when trenches pass close to structures which could be damaged by failure of the trench or excessive settlements.

A.3.3 DEPTH

For any slope other than vertical, the additional volume of soil to be excavated to slope the sides is quadrupled each time the depth is doubled. As trenches become deeper, sloping becomes less practical because of the large volume of earth involved and the increased distance from the trench centerline to the spoil pile. The maximum practical depth which can be stabilized by sloping is a function of the soil and, equally important, of the size and characteristics of the available backhoes. In some relatively deep trenches, a trench box is used to guard against collapse of the vertical-sided lower portion of the trench and the upper sides of the trench are sloped for stability. Some form of bracing is generally employed on the vertical sides cut by trenching machines when the depth exceeds four to five feet.

A.3.4 TIME AND SITE CONDITIONS

The amount of time a trench will be open, coupled with the influences of vibration, water, and soil structure, significantly affects the stability of trench sides and influences the decision between sloping and bracing. Vibrations from a number of sources can seriously reduce the stability of a soil mass. The longer the trench is open, the greater is the chance of failure. When trenching operations do not involve large pipe or special construction, trenches are seldom left open more than an hour or two, and a wide range of soils will retain adequate stability for safety with slopes as steep and 3/4 horizontal to 1 vertical. If a segment of trench is to remain open for a relatively long period, gravity forces on the exposed sides, vibrations, and other factors reduce the stability of the soil mass and either

flatter sloping or stronger bracing is required. This is particularly
true for trenches through clayey materials, where dessication and re-
sulting cracks and progressive deformation can weaken the soil struc-
ture and cause failure of a trench side which was stable when it was
initially cut. If the soil is layered and the bedding is inclined,
flatter sloping or stronger bracing of one side may be required even
when the trench is to be open for only a very short time.

A.3.5 CODES AND SPECIFICATIONS

In many cases, the choice between sloping and bracing is dictated by
codes or project plans. Areas where the water table is high and shift-
ing of material is a problem often have codes which specify that con-
duits be protected by subsurface sheeting. Bracing, rather than sloping,
is then the normal approach. Similarly, bracing is generally employed
when plans for the facility call for installation of forms for concrete
or select fill.

A.3.6 SLOPING

When determined to be the most efficient method and when right-of-way
restrictions don't preclude its use, sloping is by far the contractor's
preferred method of trench stabilization. This method requires a mini-
mum of materials and handling and provides the most reliable means of
personnel safety. Sloping is generally performed by hydraulic backhoes
unless other equipment is available. Normally the backhoe slopes the
bank back as the trench is being dug, providing a safe trench for the
workers at all times. The choice of angle to which the bank is sloped
is usually at the discretion of the backhoe operator; unless directed
by the foreman, the operator will remove soil until he is satisfied
that there is no danger of sloughing or slumping of the bank. The back-
hoe operator rarely is aware of the exact angle required by Table P-1
of the OSHA provisions [9], but instead relies on his own experience
and knowledge of the particular soil conditions.

A.3.7 SHORING

A.3.7.1 General

Shoring for trenches or narrow excavations is usually accomplished by
bracing one bank against the other. The basic shoring system includes
a sheath of wood planks or plywood placed against both sides of the
trench, horizontal members or wales placed lengthwise to support the
sheathing and a system of shores to brace the wales against the sheathing

A.3.7.2 Types of Sheathing

Skeleton Sheathing - consists of a continuous wood frame supporting
sheathing planks, placed vertically at intervals of 4-8 ft (1.2-2.4 m)

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against the trench walls. Skeleton sheathing is used where the banks consist of intact stable cohesive soils, primarily to prevent the development of initial failures, cracks or spalling.

Close Sheathing – consists of planks placed side by side along a continuous frame. Its use is to prevent local crumbling of soils. Since some space exists between the planks, it should not be used with silts or other fine grained cohesionless soils which could seep out through these cracks.

Tight Sheeting – consists of specially edged planks, generally tongue and groove, eliminating the crevices existing in close sheathing. Tight sheeting is either wood or steel and is used where water or fine wet soils must be retained. The bracing used for tight sheeting is designed for this use from the start and is generally stronger than that required for other types of sheathing.

Timber Sheet Piles – when using this system, the contractor normally leaves the piling permanently in the ground since removal usually destroys the wood's usefulness. This system consists of planks which are either square edged or tongued and grooved and which are driven into the ground before it is excavated. The toe of the piles is usually cut on a diagonal with the point on the grooved side so that in driving, each pile will be continuously wedged back against the previously driven pile. The sections are driven with the tongue leading. After driving, adjacent pieces may be spiked together across the joints to form a solid wall.

A.3.7.3 Wale Systems

Normally most contractors use large timbers for wale systems, although some steel shapes are used and recently lightweight aluminum wales have been introduced. Timber members are usually 8 x 8 in (200 x 200 mm) which are set into position at the quarter points of the sheathing and supported by cross bracing.

A. 3.7.4 Bracing Systems

Timber shores have been used extensively in the past, with sizes varying from state to state. One rule, taken from the Construction Safety Orders of the State of California pertaining to hard or compact soils, requires that bracing between wales in trenches from 5-10 ft (1.5-3 m) deep should be 4 x 4 in. (100 x 100 mm) timbers not over 5 ft (1.5 m) apart, increasing to 6 x 6 in. (150 x 150 mm) for depths over 10 ft (3 m). Other states have similar standards.

Trench jacks consist of two shoes with pronged surfaces that bear against the wale system, or in the absence of wales, directly against the sheathing. The shoes are held against the sheathing by an extendable connecting bar (usually a screw jack which can be extended). This

assembly is placed against the sheathing and extended or jacked outward, providing the necessary lateral pressure to support the sides of the trench.

Aluminum hydraulic shores - have been developed in recent years. The shore is a hydraulic cylinder either connected to aluminum bearing plates or aluminum shores. This system has the advantage of remote installation. The man installing these shores can stay outside of the trench during installation.

A.3.7.5 Skip Shoring

This method utilizes the cohesive strength of the soil along with arching effects, thereby allowing the contractor to support the wall by individual spaced timber struts, trench jacks or hydraulic shores. The use of spaced vertical or horizontal planks supported at the quarter points by two struts (cross braces) is the most common method of skip shoring. The foreman makes the onsite decision as to whether the soil has the strength required. Preliminary soils investigations give estimates of the strength, but not until the trench has been cut can an accurate estimate of the strength be made. When a soil has demonstrated its capacity to stand vertically with only skip shoring, the foreman will allow workers into the trench.

A.3.8 TRENCH BOXES

Trench boxes are rigid boxes which are placed in the trench before the entry of workers. The sidewall of the boxes are strong enough to resist the lateral soil pressures. Thus, inside the box is a protected work area. A relatively recent development in providing worker safety, trench boxes permit rapid construction work as well as providing protection for workers. Some designs allow assembly in minutes at the job site, and space saving flat storage for shipment from job to job. Contractors can use the boxes in several ways. The box can be placed in the line of excavation digging the trench from inside the box, removing the soil and subsequently pushing each side wall of the box down to the pipe grade. This technique reduces the amount of soil that must be removed, and lessens the damage to surrounding landscape. Another technique is to dig the trench in front of the box, then pull it into the new section of trench with the backhoe. The technique uses the backhoe for all phases of trenching, reducing the need for several pieces of machinery. This technique requires that the trench be dug at least a foot wider than the box so that skin friction between the box and the sidewall of the trench is reduced as much as possible. After the trench box has been pulled through a section of trench, another machine, usually a dozer, backfills the trench immediately to reduce the risk of excessive soil movement.

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A.3.9 EQUIPMENT

Backhoes are excavating machines which are primarily used to dig below
the natural surface of the ground on which the machine rests. They are
adapted to excavating trenches, pits for basements, and general grading
work which requires precise control of depths. In some respects back-
hoes are more versatile than wheel or ladder type trenching machines,
especially in digging utility trenches whose banks are sloped and for
which trench shoring will not be used. Hoes can remove the earth as
it caves in to establish stable slopes, whereas trenching machines can-
not do this easily. There are two basic types of backhoes. Track
mounted backhoes are heavy duty and are generally quite large [their
weights range from approximately 32,000 lb to 120,000 lb (14,500 kg
- 54,400 kg)]. Loaded combos are designed for more general work.
They are mounted on rubber tires and are equipped with a loader bucket
on one end and a backhoe bucket on the other.

Trenching machines are primarily used for digging utility trenches for
water, gas, and oil pipelines, telephone cables, drainage ditches, and
sewers where the job and soil conditions are such that they may be used.
They are capable of relatively fast digging with accurate controls of
depths and widths of trenches which reduces expensive hand finishing to
a minimum. Trenching machines are usually crawler-mounted to increase
their stability and to distribute their weight over a greater area.

There are three basic types of trenching machines. A wheel-type trench-
ing machine consists of a power-driven wheel, on which are mounted a
number of removable buckets, equipped with cutter teeth. The machine
is operated by lowering the rotating wheel to the desired depth, while
the unit moves forward slowly. The earth is picked up by the buckets
and deposited into an endless belt conveyer, which can be adjusted to
discharge the earth on either side of the trench.

Continuous-chain trenchers are designed for fairly shallow, narrow
trenches using digging scoops along a chain. The chain is supported on
a boom attached to the rear end of the prime moving tractor unit. The
major disadvantage of continuous-chain trenchers is that the lack of
rigidity in the chain prevents the buckets from digging into tough
material; they tend to twist over or move out of such earth. Only in
loose materials can the buckets be expected to get full loads.

The third variety is the ladder type trenching machine. It combines
the advantages of a wheel trencher and a continuous-chain trencher.
A ladder like projecting frame serves as the boom which can be raised
or lowered into the excavated trench. The excavation depth can thus
be adjusted while moving. The ladder type trencher can therefore oper-
ate on a more irregular surface than the wheel type. It has two con-
tinuous chains on both sides of the projecting frame with buckets like
those on the wheel trencher attached to and between the two chains.
In this way it can achieve the high production rates, lateral rigidity,
and power of the wheel trencher.

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A.3.10 CONTRACTOR CHARACTERISTICS

In current practice in the United States, trenching is by and large a
local operation. Utility contractors seldom bid on projects which are
located more than 50 to 75 miles from their home base. Significant
exceptions to this arrangement are the general contractors who have a
trenching division and often move their trenching crews to other
localities when their projects include trenches. Other exceptions are
the large pipeline projects, which attract bidders from all over the
country.

Since they normally concentrate their work in a relatively small area,
utility contractors have considerable knowledge of the physical charac-
teristics of the soils in their area. They are not concerned with
classical identification procedures; the fact that a given soil con-
tains certain percentages of clay, mica, sand, and other materials is
of only incidental interest to them. Instead, they rely on their per-
sonal experience and the experiences of their fellow contractors in
the area for deciding on the extent of sloping or bracing required
for a trench in a given locality during a given season of the year.
Their experience and knowledge also enables them to predict, with fair
accuracy, the problems they will encounter with subsurface water and
rock formations.

Contractors have only limited confidence in soil boring results. When
there is some doubt about the conditions they will encounter, many con-
tractors, either individually or in cooperation with other bidders, dig
several test pits with backhoes along the trace of the project to obtain
the additional information they need in order to submit intelligent
bids. Presence of subsurface water and rock are primary concerns,
but the contractors also obtain additional information on site stability
from the digging process and from leaving the pits open several hours.

As indicated previously, utility contractors tend to specialize in one
type of trenching work. Their machinery and the experience of their
crews are a fundamental element in their decision to obtain stability
by sloping or by bracing.

In all but the very large diameter lines, pipe-laying is a dynamic oper-
ation, moving along at the rate of several hundred or more feet per day.
Soil structure, moisture content, and related factors change constantly
and the frequency of significant changes increases rapidly with
increases in the rate of production. Decisions on stability must not
only be made accurately, but also promptly, if the contractor is to
be successful. As a consequence, most firms rely on their job foremen
and equipment operators for day-to-day decisions on sloping and bracing.
Although these people are normally neither engineers nor soils techni-
cians, confidence in their judgment appears to be well-deserved in most
cases. The foreman with 20 or more years of experience in trenching
is the rule; 10 years or less is the exception. Foremen normally know
as much, if not more, about the physical characteristics of the soil

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in their local area as the knowledge that could be obtained through conventional soil exploration and laboratory tests. Some contractors solve their bracing problems by simply stockpiling standard sizes of timber on site for use when and if the foreman decides that bracing is necessary. Bracing methods developed by the firm from experience with soils in the area are normally employed without detailed design and analysis.

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15. SUPPLEMENTARY NOTES

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

Construction practices in trenching and data on potential causes of trenching accidents are reviewed. A study is made of the soil properties and site conditions that must be identified in order to determine the stability of shored and sloped excavations against cave-ins. Two possible alternate soil classification methods are recommended, which are simple enough to be used by construction foremen and at the same time use parameters which can be measured or identified without ambiguity. The classification methods are supplemented by appropriate field tests.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

Braced excavations; construction; excavation; geotechnical engineering; retaining structures; shoring; slope stability; soil classification; soil pressure; soil testing; trenching.

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